Lipid rescue: the use of lipid emulsions to treat local anaesthetic toxicity

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The discovery of lipid rescue: serendipity and science

Weinberg and colleagues proposed and subsequently elucidated the mechanisms behind the use of lipid emulsion as an adjunctive therapy in local anaesthetic cardiotoxicity (Table I). The initial animal work was prompted by their observation of severe ventricular dysrhythmias after subcutaneous administration of only 22 mg of bupivacaine to a “carnitine deficient” adolescent. This chance observation prompted investigation of the relationship between bupivacaine toxicity and the underlying metabolic abnormality. Weinberg’s initial proposal, that lipid pre-treatment would aggravate bupivacaine-induced cardiac arrhythmias, was based on studies indicating that intracellular accumulation of free fatty acid derivatives during myocardial ischaemia contributes significantly to ischaemia-induced arrhythmias. However, a series of experiments designed to test this hypothesis indicated that instead of aggravating dysrhythmias, lipid emulsion therapy favourably shifted the dose response curve of bupivacaine-induced asystole. In this rat model, administration of large (15 mg/kg) intravenous dosages of bupivacaine resulted in all lipid-treated animals surviving while all saline-treated controls perished. A subsequent canine study confirmed these favourable results. While all dogs in the control group perished after 10 mg/kg bupivacaine, rapid normalisation of haemodynamic parameters with uniform survival was observed in the lipid-treated animals. The latter study also demonstrated significant improvements in myocardial tissue oxygen tension and pH after lipid treatment.

The findings of this canine study prompted Weinberg to test a novel hypothesis of the mechanism of lipid emulsion in local anaesthetic cardiotoxicity. The hypothesis stated that local anaesthetic-induced cardiotoxicity occurred because of inhibition of the carnitine-dependent processes that transport long-chain fatty acids into the mitochondrial matrix. These processes are essential for the production of energy by the electron transport chain. Lipid emulsion may act to enhance the intracellular availability of these long-chain fatty acids, thus supporting energy production and limiting the effects of local anaesthetic cardiotoxicity.

**Table 1** Mechanisms of cardiotoxicity of local anaesthetic agents

1. **Mechanisms causing cardiac rhythm disturbances, particularly with bupivacaine, include the following**
   - a. Ion channel blockade:
     - i. Blockade of sodium channels which inhibits myocardial depolarisation.
     - ii. Blockade of the transient outward potassium current (Ito) which inhibits repolarisation of cardiac myocytes.
     - iii. Blockade of the voltage-dependent calcium channels, thereby limiting sarcoplasmic calcium release.
     - iv. Even though both lignocaine and bupivacaine exhibit dose-dependent blockade of the cardiac voltage-gated sodium channels, Clarkson and Hondeghem suggested that the greater cardiotoxicity of the latter is attributed to its strong binding to resting and inactivated sodium channels. Furthermore, local anaesthetic agents bind to and dissociate from sodium channels during systole and diastole respectively. Thus at normal heart rates lignocaine can dissociate completely during diastole, but there is insufficient time for bupivacaine to dissociate from sodium channels. Clinically this often presents as prolongation of the QRS complex and ventricular dysrhythmias and tachycardia.
   - b. Depression of conduction in the brainstem area that controls cardiac sympathetic outflow, the nucleus tractus solitarius, leads to hypotension and dysrhythmias.

2. **Myocardial depression may result from the following**
   - a. Decreased myocardial calcium release from the sarcoplasmic reticulum and inhibition of calcium excitation-contraction coupling.
   - b. Na+/Ca++ exchange pump function is inhibited with decreased cytosolic calcium.
   - c. Inhibition of -adrenergic receptor function.
   - d. Inhibition of almost every aspect of oxidative phosphorylation, and complexes 1 and 2 of the electron transfer chain.
   - e. Inhibition of nucleus tractus solitarius. (Nonetheless, myocardial depression is not usually pronounced even in severe toxicity.)

3. **A significant cause of hypotension is due to vasodilatation because of both of the following**
   - a. Direct vasodilatation.
   - b. Powerful inhibition of peripheral sympathetic reflexes.

(For more detail, see Dippenaar JM. Local anaesthetic toxicity. SAJAA 2007;13(23):92)
free fatty acids into the mitochondrial matrix. This blockade resulted in reduction in the availability of intra-mitochondrial long-chain fatty acids for myocardial oxidative metabolism. Increasing plasma lipid concentrations would, by virtue of mass action, counteract the problematic effects of local anaesthetics on carnitine transport (Figure 1). The Weinberg group could indeed prove their hypothesis that bupivacaine-induced inhibition of carnitine-acylcarnitine translocase and carnitine-dependent mitochondrial long-chain fatty acid transport occurred in isolated mitochondria at clinically relevant toxic concentrations.9 Furthermore, indirect evidence supporting the validity of this mechanism may be that the potency of inhibition of transport of lipid fuel into mitochondria by local anaesthetics parallels their ability to generate cardiotoxicity.9

**Figure 1** Carnitine-dependent, long-chain fatty acid transport across the mitochondrial membrane
The carnitine palmitoyltransferase (CPT1 and CPT2) system facilitates specifically long-chain fatty acid entry into subcellular organelles, particularly mitochondria.86 This mechanism is of particular importance in generating sufficient ATP from fats because only short- and medium-chain fatty acids (length) can enter mitochondria by passive diffusion.

**Step 1:** Long-chain-specific carnitine acyltransferase (CPT1) activity in the cytosol results in the acyl moiety of acyl-CoA and carnitine being esterified to form acylcarnitine.87

**Step 2:** Carnitine-acylcarnitine translocase (CACT) facilitates transfer of acylcarnitine to the mitochondrion.86

**Step 3:** In the mitochondrion, CPT2 uncouples acylcarnitine. The fatty acids now in the mitochondria are esterified to CoA. Acyl-CoA that is produced is subsequently utilised in fatty acid oxidation in the Krebs/tricarboxylic acid cycle.10,86

**Step 4:** Mitochondrial carnitine released in step 3 is transferred back into the cytosol by CACT. Bupivacaine and other local anaesthetic agent toxicity block the carnitine transporter system, thereby limiting the entry of long-chain fatty acids into the mitochondrion. In the heart, as opposed to other organs, more than 80 to 90% of normal aerobic cardiac metabolism results from fatty acid oxidation, ketones and lactate.1,28,90 The disproportionate cardiotoxicity relative to the neurotoxicity of bupivacaine can be related to cardiac preference for lipid compared to the brain’s preference for carbohydrates as fuel sources.32 It may also explain why bupivacaine and other local anaesthetic cardiotoxicity is so very resistant to therapy.1
Weinberg’s canine experiments elicited upbeat editorial comment. Groban and Butterworth questioned whether lipid emulsion therapy indeed represented a “silver bullet” for treating bupivacaine cardiotoxicity. They proposed that lipid emulsion be employed in human bupivacaine intoxication only “after other, more conventional treatments had proven unsatisfactory” as these observations in animals, albeit striking, were yet to be confirmed.

The first human case describing resuscitation from local anaesthetic-induced cardiotoxicity facilitated by lipid emulsion was reported by Rosenblatt and colleagues almost a decade after Weinberg’s initial report. This case describes asystole with paroxysms of ventricular tachycardia after 100 mg bupivacaine and 300 mg mepivacaine had been administered as an interscalenar brachial plexus block. The arrhythmias were refractory to multiple drug therapy and counter shocks. After 30 minutes of unsuccessful resuscitation as a last resort before initiating cardiopulmonary bypass, 100 ml of 20% Intralipid® was administered intravenously. Within seconds of completion of the lipid emulsion bolus, return of spontaneous circulation and a normal blood pressure occurred. The patient survived without neurological deficit.

The salient features of other published case reports are outlined in Table II. All case reports describe rapid recovery when lipid emulsion therapy was employed to facilitate resuscitation following local anaesthetic-induced cardiotoxicity. The case reports indicate efficacy of lipid emulsion therapy with the majority of amide local anaesthetics currently in clinical use, including bupivacaine, mepivacaine, ropivacaine, levobupivacaine and lignocaine. It is interesting to note that despite the benign reputation of ropivacaine, other case reports include references to ropivacaine-induced cardiotoxicity. Other insights gained by studying these cases are that although Intralipid® is the most commonly used agent other lipid emulsions (Medialipid® and Liposyn®) have also been employed successfully for lipid rescue. Furthermore, the first patients rescued with the help of lipid emulsions had severe concomitant disease (ischaemic heart disease, advanced age, pulmonary disease, end-stage renal disease). It is not surprising that regional anaesthesia was employed in these patients.

Mechanisms of lipid rescue

Two theories, namely the lipid sink and lipid flux theories, dominate the current understanding of the mechanisms of lipid rescue. The lipid sink theory hypotheses that highly lipophlic drugs sequestrate into the "newly created intravascular lipid compartment." This theory originated from early rat experiments in which myocardial bupivacaine concentrations decreased rapidly after lipid rescue. Later work confirmed more rapid clearance of bupivacaine from rat myocardium when lipid emulsion therapy was compared to control. Support for this theory also comes from a lipid-aqueous ratio of bupivacaine in an Intralipid®-plasma mixture of 11.9 to 1 and the ability of lipid emulsions to terminate convulsions. If the lipid sink hypothesis holds true, serum local anaesthetic concentrations should increase after lipid rescue. This was not borne out by the second case described by Litz, where a decrease in bupivacaine concentrations was observed after lipid rescue.

The lipid flux theory is based on the powerful ability of local anaesthetics to inhibit the carnitine transporter system, the enzyme system responsible for transfer of long-chain fatty acids into the mitochondrial matrix for β-oxidation. Administration of lipid emulsion provides medium- and short-chain fatty acids to supply the mitochondria with sufficient substrate. Weinberg suggests that restoring the heart’s preferred fuel supply (fatty acids) could explain why resuscitation is so rapid following lipid emulsion.

There is collateral evidence supporting the lipid flux hypothesis. Firstly, in an isolated rat heart model of bupivacaine cardiotoxicity, Stehr and colleagues demonstrated improved myocardial contractility at plasma concentrations of lipid far lower than that needed to provide a lipid sink effect. Secondly, the promotion of substrate influx into cells that follow administration of insulin (2 IU/kg) combined with glucose and potassium invokes mechanisms that parallel that of the lipid flux theory.

Insulin and reversal of local anaesthetic-induced cardiotoxicity

The hypothesis that insulin, glucose and potassium infusion can be a useful adjuant in resuscitation from bupivacaine cardiotoxicity has been confirmed in two animal studies. Because the dosage of insulin employed was 2 IU/kg, anaesthesiologists have been extremely hesitant to translate this research into clinical practice. The beneficial effects of insulin in the presence of local anaesthetic cardiotoxicity include promotion of the transient outward potassium current, intracellular potassium movement – which causes hypokalaemia – and an increase in the rate of depolarisation of the slope of phase zero (Vmax) of the cardiac action potential. Insulin will also facilitate sarcoplasmic calcium transport because of calcium adenosine triphosphatase activation. The first two mechanisms have antarrhythmnic actions while the increased calcium flux helps counteract deleterious effects of local anaesthetics on myocardial contractility. However, Weinberg and Vadelloncouer suggested that insulin and lipid act via similar mechanisms in local anaesthetic cardiotoxicity. The increase in glycolysis and glucose oxidation that follows insulin administration may be the driver that provides sufficient substrate for oxidative phosphorylation and adenosine triphosphate (ATP) production.

The availability of lipid emulsion and preparedness to use it

In 2006, Corcoran and colleagues surveyed the preparedness of 135 academic anaesthesiology departments in the USA to employ lipid rescue. Seventy-four per cent of the departments reported they would not consider using lipid emulsion therapy for local anaesthetic cardiotoxicity. However, only one year after the first case report, Williamson and Haines reported that three-quarters of labour wards in the United Kingdom already had lipid emulsion available or planned to stock it. The difference between these studies may well be that the first study was performed before publication of the first successful human lipid rescue. The UK study also questioned why lipid emulsion was not available. The three main reasons cited for the unavailability of lipid emulsion were that the evidence base was not strong enough to justify clinical use, that lipid was not considered necessary, and that anaesthesiologists were unaware of the research regarding lipid rescue. While the first reason may be debated, the last two points are disconcerting and represent a significant reason for the publication of review articles on this topic.

Picard and Meek point to parallels between the anaesthesia community’s initial reluctance to embrace lipid rescue and the slow initial clinical acceptance of dantrolene for treatment of malignant hyperthermia. Because of the rarity and severity of local anaesthetic-induced cardiotoxicity, it is not possible or ethical to conduct human research on the underlying problem. Human case reports describing successful lipid rescue are therefore invaluable.

When should lipid therapy be started?

The initial recommendations stated that lipid rescue be employed “only after other, more conventional treatments have proven unsatisfactory” or that it “should be considered before ceasing resuscitative efforts even if its use is contemplated after a significant delay in the setting of prolonged cardiac arrest.” As confidence with this therapeutic modality grows, case reports indicate progressively earlier administration of lipid emulsion during resuscitation. This has led Weinberg to retract his earlier conservative recommendation “that lipid infusion be delayed until standard resuscitative measures failed.”

What are the implications of earlier institution of lipid therapy in the presence of local anaesthetic toxicity? Should lipid
<table>
<thead>
<tr>
<th>Case</th>
<th>Local anaesthetic</th>
<th>Time to first symptoms after local anaesthesia injection</th>
<th>Presenting feature</th>
<th>Cardiac arrest, electrical or conduction changes?</th>
<th>Timing of lipid administration</th>
<th>Total duration of CPR before ROSC†</th>
<th>Dose of lipid</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Rosenblatt et al. 2006</td>
<td>Bupivacaine 100 mg plus mepivacaine 300 mg</td>
<td>30 seconds</td>
<td>Incoherence and convulsions</td>
<td>Asystole</td>
<td>After 20 minutes CPR</td>
<td>20 minutes</td>
<td>100 ml of 20% solution of Intralipid® as a bolus followed by 0.5 ml/kg/min for 2 hours (about 4900 ml in total)</td>
<td>Sinus rhythm restored very quickly (15 seconds) after administration of bolus. Patient survived without sequelae</td>
</tr>
<tr>
<td>2) Litz et al. 2006</td>
<td>Ropivacaine 400 mg (axillary plexus block)</td>
<td>15 minutes</td>
<td>Dizziness, drowsiness, loss of consciousness, convulsions</td>
<td>Ventricular extrasystoles, bradycardia, asystole</td>
<td>After 10 minutes CPR</td>
<td>20 minutes</td>
<td>100 ml of 20% solution of Intralipid® as a bolus followed by infusion of 10 ml per minute</td>
<td>Return of electrical activity (initially broad complex tachyarrhythmia) after 200 ml Intralipid®. Patient survived without sequelae</td>
</tr>
<tr>
<td>3) Foxall et al. 2007</td>
<td>Levobupivacaine 100 mg (lumbar plexus block)</td>
<td>Seconds</td>
<td>Unresponsiveness and convulsions</td>
<td>No cardiac arrest, reduced QRS voltage and broadening of QRS complexes</td>
<td>4 minutes after administration of block</td>
<td>Not applicable. “Rapid normalisation” of QRS morphology with infusion</td>
<td>100 ml Intralipid® over 5 minutes</td>
<td>Patient survived without sequelae</td>
</tr>
<tr>
<td>4) Zimmer et al. 2007</td>
<td>Bupivacaine 15 mg bolus followed 20 minutes later by 26 mg fractionated over 15 minute period (epidural anaesthesia during labour)</td>
<td>15-20 minutes after last bupivacaine bolus</td>
<td>Shivering, central nervous system excitation</td>
<td>No cardiac arrest, supraventricular tachycardia, ventricular extrasystoles</td>
<td>45 minutes after last bupivacaine bolus</td>
<td>Not applicable.</td>
<td>100 ml 20% Liposyn III® followed by infusion 0.5 ml/kg/hr</td>
<td>Blood in epidural catheter after aspiration</td>
</tr>
<tr>
<td>5) Spence 2007</td>
<td>Lignocaine 90 mg plus bupivacaine 0.5 mg (epidural analgesia during labour)</td>
<td>90 seconds after last bolus</td>
<td>Reassess, agitation, twitching</td>
<td>No report of any ECG or circulatory changes</td>
<td>Not specified</td>
<td>Not applicable. Fully conscious within 90 seconds of administration</td>
<td>100 ml 20% Intralipid® bolus over 60 seconds followed by 400 ml over 15 minutes</td>
<td>Letter to the editor Intravascular catheter “migration” and blood able to be subsequently aspirated from catheter</td>
</tr>
<tr>
<td>6) McCutchen et al. 2008</td>
<td>Ropivacaine 150 mg (brachial plexus block) plus bupivacaine 150 mg (axillary nerve block)</td>
<td>20 seconds</td>
<td>Convulsions</td>
<td>Ventricular tachycardia with pulse and respiratory effort</td>
<td>3 minutes after second convolution</td>
<td>No CPR administered</td>
<td>100 ml 20% Intralipid® bolus over 60 seconds followed by 400 ml over 15 minutes</td>
<td>Possible overdose of local anaesthetic agents. Mental state normal in 2 hours</td>
</tr>
<tr>
<td>7) Ludot et al. 2008</td>
<td>Lignocaine 110 mg plus ropivacaine 82.5 mg (lumbar plexus block)</td>
<td>15 minutes</td>
<td>Ventricular tachycardia</td>
<td>Ventricular tachycardia</td>
<td>Not specified</td>
<td>Not applicable. Rhythm recovered 2 minutes after starting lipid</td>
<td>Mediafil® 20% 150 ml over 5 minutes</td>
<td>Patient under general anaesthesia while block administered</td>
</tr>
<tr>
<td>8) Litz et al. 2008</td>
<td>Mepivacaine 500 mg (infraclavicular) augmented 15 minutes later by prilocaine 100 mg (axillary block)</td>
<td>Within 5 minutes of second injection</td>
<td>Dizziness, nausea, agitation</td>
<td>Heart rate increase from 76 to 92, supraventricular extrasystoles, paroxysms of ventricular bigeminus</td>
<td>Not specified</td>
<td>Not applicable</td>
<td>Intralipid® 20%. Bolus 50 ml repeated after 5 minutes. Infusion 0.25 ml/kg/hr of a further 100 ml</td>
<td>Regained consciousness within 5 minutes of starting Intralipid®. Extrasystoles gone after approximately 200 ml (10 minutes) of Intralipid® infused</td>
</tr>
<tr>
<td>9) Warren et al. 2008</td>
<td>Mepivacaine 450 mg plus ropivacaine 50 mg (supraclavicular brachial plexus block)</td>
<td>5 minutes</td>
<td>Laboured breathing, apnoea, unresponsiveness</td>
<td>Ventricular fibrillation, Torsades des pointes</td>
<td>Infusion started 10 minutes after CPR commenced</td>
<td>25 minutes</td>
<td>Liposyn III 20%. No bolus administered. 250 ml infused over 30 minutes</td>
<td>The omission of a bolus probably resulted in delayed lipid effect. 26 defibrillations Survived intact</td>
</tr>
<tr>
<td>10) Smith et al. 2008</td>
<td>Bupivacaine 155 mg with epinephrine 1:400 000 and clonidine 100 μg (axillary nerve block)</td>
<td>Immediate</td>
<td>Loss of consciousness and tonic-clonic seizure</td>
<td>Asystole</td>
<td>Within first minute of asystole</td>
<td>5 minutes</td>
<td>Bolus 250 ml Intralipid® 20% over 2 minutes. Infusion Intralipid® 20% 15 ml/min, duration not stated</td>
<td>Patient awake and responsive by 90 minutes</td>
</tr>
<tr>
<td>11) Marwick et al. 2009</td>
<td>Bupivacaine 150 ml Intralipid 20% over 1 minute. Infusion Intralipid 250 ml 20% over 40 minutes</td>
<td>Immediate</td>
<td>Convulsions</td>
<td>Ventricular fibrillation</td>
<td>Within first minute of asystole</td>
<td>5 minutes</td>
<td>Bolus 150 ml Intralipid® 20% over 1 minute. Infusion Intralipid 250 ml 20% over 40 minutes</td>
<td>Recurrence of cardiotoxicity</td>
</tr>
</tbody>
</table>

Table II: Published cases in which lipid rescue has been employed

*All information is extracted as accurately as possible from published case reports
†All ROSC: return of spontaneous circulation
emulsion be administered only after the occurrence of cardio toxicity, only after cardiac arrest or only after failed resuscitation occurs? Another pertinent question is whether lipid should be administered immediately after local anaesthetic-related neurotoxicity? Convulsions secondary to local anaesthetic toxicity are usually easily managed and, in isolation, are probably not strong indications for use of lipid rescue. However, it is well described that bupivacaine-induced cardiotoxicity occurs in closer relationship to neurological signs than is the case with other local anaesthetic agents. The recommendations for commencement of lipid emulsion therapy by Weinberg (Figure 2) and the Association of Anaesthetists of Great Britain and Ireland (AAGBI) (Figure 3) are as follows:

1. Commence therapy at the first signs of local anaesthetic-induced cardiotoxicity. Preferably administer the lipid while a spontaneous circulation is still present.
2. We and others further argue that bupivacaine-induced neurotoxicity may well be an indication to administer lipid emulsion.

Protocol for therapy

As yet, no standard protocol for lipid emulsion therapy exists. In the presence of local anaesthetic toxicity, both AAGBI and Weinberg, on the lipid rescue website, currently recommend administration of an initial bolus of 1.5 ml/kg of 20% lipid emulsion over one minute. The bolus may be repeated twice at five-minute intervals if an adequate circulation has not been restored or if asystole persists.

Both aforementioned sources recommend following the bolus with an infusion of 20% lipid emulsion at 0.25 ml/kg/minute. While AAGBI and Weinberg both recommend continuing the infusion, the former recommends doing this over a 20-minute period (i.e. finishing the rest of the 500 ml bag over this time) while the latter recommends the infusion be continued for 50 to 60 minutes. The infusion rate may be increased to 0.5 ml/kg/minute should an adequate circulation not be restored. Notwithstanding the nuances of a particular dosing regimen, the lipid infusion should be continued until a stable and adequate circulation has been restored.

Practitioners are frequently uncertain of the dose of lipid emulsion to be administered during resuscitation. To prevent such uncertainty, both Weinberg and the AAGBI have recommended that dosing instructions should be attached to the stock of lipid held for treating local anaesthetic toxicity.

Reoccurrence of toxicity

Following inadvertent bupivacaine intoxication, we experienced a case of reoccurrence of cardiotoxicity. The phagocytosis process produces reactive oxygen species, the liver being the principal organ injured in this process. Shortly after commencement of infusion of an unstable lipid emulsion, a pyrogenic response typified by fever, chest pain and signs of an anaphylactic-type reaction can manifest. This type of reaction is rare now due to improved manufacturing processes. Subacute reactions resulting from microvascular obstruction present as hepatic dysfunction due to impaired hepatic perfusion and dysfunction.

Safety considerations regarding lipid emulsion administration

Lipid emulsions used for total parental nutrition are commonly 20% soybean oil emulsions that are classified according to droplet size. Micro-, mini- and macro-emulsions have mean droplet sizes less than 0.1 μm, less than 1 μm and greater than 1 μm respectively. The mini-emulsion is the most commonly used soybean oil formulation for total parental nutrition. Soybean emulsions are stabilised by addition of emulsifiers (typically egg phospholipids) that possess hydrophobic and hydrophilic heads that coat the submicron droplet. Three physicochemical factors, namely pH, free fatty acid concentration and globule size, influence the stability of lipid emulsions. Progressive degeneration of long-chain triglycerides to free fatty acids results in a pH of 9 immediately after manufacturing, decreasing to a pH of 6 toward the end of the 24-month shelf life. Decreases in pH reduce phospholipids' anionic electrostatic charge, causing instability and promoting lipid droplet coalescence. Lipid droplets smaller than one micron in diameter are metabolised by lipoprotein lipase located in the vascular endothelium. Larger globules that form in unstable infusions are phagocytosed by macrophages of the reticuloendothelial system. The phagocytosis process produces reactive oxygen species, the liver being the principal organ injured in this process. Shortly after commencement of infusion of an unstable lipid emulsion, a pyrogenic response typified by fever, chest pain and signs of an anaphylactic-type reaction can manifest. This type of reaction is rare now due to improved manufacturing processes. Subacute reactions resulting from microvascular obstruction present as hepatic dysfunction due to impaired hepatic perfusion and dysfunction.

Even rapid administration of large doses of stable lipid emulsion can have potential side-effects, which may be aggravated by the presence of high plasma levels of local anaesthetic agents. Local anaesthetics induce myocardial depression, even at levels found in normal clinical use. Myocardial depression will be aggravated by increases in both right and left ventricular afterload that are associated with both lipid emulsion therapy and local anaesthetic toxicity. Local anaesthetic toxicity increases centrally mediated sympathetic nervous system outflow, thereby increasing left ventricular afterload. Lipid emulsion may induce vasoconstriction secondary to inhibition of nitric oxide.
Signs of severe toxicity:
• Sudden loss of consciousness, with or without tonic-clonic convulsions
• Cardiovascular collapse: sinus bradycardia, conduction blocks, asystole and ventricular tachyarrhythmias may all occur
• Local anaesthetic LA toxicity may occur sometime after the initial injection

Immediate management:
• Stop injecting the LA
• Call for help
• Maintain the airway and, if necessary, secure it with a tracheal tube
• Give 100% oxygen and ensure adequate lung ventilation (hyperventilation may help by increasing pH in the presence of metabolic acidosis)
• Cardiopulmonary resuscitation is necessary
• Control seizures: give a benzodiazepine, thiopental or propofol in small incremental doses
• Assess cardiovascular status throughout

Treatment of cardiac arrest with lipid emulsion (approximate doses are given in ml for a 70-kg patient)
• Give an intravenous bolus injection of Intralipid® 20% 1.5 ml.kg⁻¹ over 1 min
  a. Case 1: 150 ml over 1 min
  b. Continue CPR
• Start an intravenous infusion of Intralipid® 20% at 0.25 ml.kg⁻¹ min⁻¹
  a. Case 2: 400 ml over 20 min
  b. Repeat the bolus injection twice at 5 min intervals if an adequate circulation has not been restored
• After another 5 min, increase the rate to 0.5 ml.kg⁻¹ min⁻¹ if an adequate circulation has not been restored
  a. Case 3: 400 ml over 10 min
  b. Continue infusion until a stable and adequate circulation has been restored

Remember:
• Continue CPR throughout treatment with lipid emulsion
• Recovery from LA-induced cardiac arrest may take up to 1 h
• Propofol is not a suitable substitute for Intralipid®
• Replace your supply of Intralipid® 20% after use

Follow-up action:
• Report cases from the United Kingdom to the National Patient Safety Agency (www.npsa.nhs.uk). Cases from the Republic of Ireland should be reported to the Irish Medicines Board. Whether or not lipid emulsion is administered, also please report cases to the LipidRescue™ site www.lipidrescue.org.
• If possible, take blood samples into a plain tube and a heparinized tube before and after lipid emulsion administration and at 1 h intervals afterwards. Ask your laboratory to measure LA and triglyceride levels (these have not yet been reported in a human case of LA intoxication treated with lipid).
• Please read the notes overleaf

Your nearest bag of Intralipid® is kept .................................................................

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Available online at: http://www.aagbi.org/publications/guidelines/docs/latoxicity07.pdf

REPRODUCED WITH THE KIND PERMISSION OF THE ASSOCIATION OF ANAESTHETISTS OF GREAT BRITAIN AND IRELAND
1. Pertinent schools of thought exist: Use of lipid rescue is effective and superior to protocols. However, current American Heart Association and in effecting resuscitation over saline controls. These studies the superiority of lipid in reducing the toxic dose of bupivacaine administration of half to one litre of 1% propofol. The also produce adverse reactions. These include aggravation

Lipid emulsions infused as part of total parenteral nutrition can also produce adverse reactions. These include aggravation of hypoxia due to impairment of hypoxic pulmonary vasoconstriction and oxygen diffusion capacity and increasing tissue oxygen consumption. In addition, allergic reactions, thrombophlebitis, muscle weakness, seizures in children, increased intracranial pressure after traumatic head injury, warfarin resistance (because lipids facilitate the anticoagulant binding to albumin), and impaired immune, reticuloendothelial and inflammatory responses have all been reported.

**Availability of lipid emulsions in southern Africa**

Intralipid® (Fresenius Kabi, South Africa) is available as a 20% solution and is packaged in 100 ml and 500 ml bags. It has a shelf life of 18 months from the date of manufacture.

**The use of propofol for lipid rescue**

Propofol has been touted as a source of lipid in local anaesthetic toxicity. Propofol is poorly water soluble and is dissolved in the same emulsion used for lipid rescue and total parenteral nutrition. However, to deliver adequate doses of lipid will require administration of half to one litre of 1% propofol. The accompanying huge propofol dose will undoubtedly result in severe haemodynamic side effects due to vasodilatation and myocardial depression. Propofol interferes with mitochondrial functioning by inhibiting carnitine palmitoyltransferase-I and inhibiting electron transport by causing failure of the respiratory chain at complex II. The use of propofol to manage patients with local anaesthetic toxicity (either for sedation, termination of convulsions, or as a source of lipid) may aggravate local anaesthetic cardiotoxicity and is considered to be contraindicated.

**CPR, vasopressors and local anaesthetic (bupivacaine) cardiotoxicity**

Weinberg and colleagues' early animal experiments demonstrated the superiority of lipid in reducing the toxic dose of bupivacaine and in effecting resuscitation over saline controls. These studies did not employ adrenaline as part of their resuscitation protocols. However, current American Heart Association Advanced Cardiac Life Support protocol advocates the use of adrenaline during CPR. These conflicting approaches have initiated research regarding the relevant role of lipid in resuscitation. The main question currently is whether lipid emulsion should be used alone or be combined with vasopressin as adrenaline during local anaesthetic-induced cardiac arrest. Currently, four pertinent schools of thought exist:

1. **Use of low-dose adrenaline alone is effective to treat local anaesthetic (bupivacaine) toxicity**. In an instructive letter to the editor, Moore* argued that aggressive maintenance of the circulation by treatment of bradycardia with small (300 µg to 500 µg) intravenous boluses of epinephrine and the early institution of CPR solves most cases of bupivacaine-related cardiotoxicity, without requiring recourse to lipid emulsion therapy. This approach has support from animal experiments.

2. **Use of lipid rescue is effective and superior to vasopressor therapy in local anaesthetic toxicity**. Weinberg and colleagues and Di Gregorio and colleagues demonstrated the superiority of lipid emulsion therapy over epinephrine in bupivacaine-induced cardiac arrest models. The reasons elucidated for achieving better results with lipid were superior cardiac and metabolic function during and after resuscitation, and adrenaline-induced aggravation of bupivacaine-related dysrhythmias. However, rats treated with adrenaline showed a decline in haemodynamics after 10 minutes.

3. **Lipid rescue is effective, but exceeding particular doses of adrenaline impede the effectiveness of resuscitation**. Recent investigations described a threshold effect of adrenaline on survival in local anaesthetic toxicity and lipid rescue. When doses exceeding 10 µg/kg were administered, adrenaline impaired long-term success of lipid resuscitation after bupivacaine intoxication. Hicks and colleagues’ study, discussed below, may also be relevant here. The reasons suggested for the poor outcome with higher dosages of adrenaline include the development of pulmonary oedema, lactic acidosis and increased myocardial work.

4. **Lipid rescue is not superior to the use of vasopressor in local anaesthetic systemic toxicity**. Mayr and colleagues observed that vasopressin or adrenaline or a combination of the two was successful while lipid emulsion alone was uniformly unsuccessful in effecting resuscitation in a porcine model of bupivacaine cardiotoxicity. The explanation offered for the divergent successes of lipid versus vasopressor therapy focussed on study design. Mayr and colleagues introduced a period of apnoea after bupivacaine administration while in the Weinberg and Di Gregorio studies hypoxia and delay in resuscitation were avoided. Hicks and colleagues employed a swine model of bupivacaine-induced cardiac arrest in which a high dose of adrenaline (100 µg/kg) was administered and a one-minute period of apnoea was allowed before resuscitation commenced. Lipid emulsion did not improve the rate of return of spontaneous circulation when added to epinephrine and vasopressin.

What clinically relevant conclusions can be drawn from these divergent results? Cave and Harvey commented that lipid emulsion therapy is superior to vasopressor therapy, despite the results of Mayr’s and Hick’s studies being confounded by asphyxiation. Weinberg still advocates following the American Heart Association Advanced Cardiac Life Support protocol advocating the use of adrenaline. Whether the findings of rodent studies will result in adrenaline dose modification during CPR in humans, or only during lipid emulsion therapy, is at present not clear. It is interesting that investigations into the place of vasopressor use in lipid rescue from local anaesthetic toxicity may have wider ramifications in terms of current resuscitation practices. We believe that the American Heart Association Advanced Cardiac Life Support protocol should specify that local anaesthetic cardiotoxicity is an indication for lipid emulsion therapy.

**The use of lipid emulsions to reverse toxicity of other drugs**

Lipid emulsion therapy reliably reverses cardiotoxicity caused by a variety of lipophilic drugs, including tricyclic antidepressants, calcium channel blockers, propranolol and thiopentone. Case reports have been published on successful lipid rescue following cardiotoxicity involving haloperidol, bupropion and lamotrigine. The lipid sink mechanism has been suggested to be the predominant mechanism responsible for facilitating resuscitation. Brent has gone as far as stating that lipid emulsion therapy should be attempted before resuscitation is abandoned in lipophilic drug-induced cardiotoxicity. However, concerns have been raised whether lipid could interfere with the efficacy of amiodarone and other drugs used during resuscitation.

**Limitations and perspectives on lipid emulsion therapy for local anaesthetic cardiotoxicity**

It should be emphasised that lipid therapy is an adjunct to and not a substitute for basic resuscitation measures. Failures of lipid rescue in local anaesthetic cardiotoxicity have not yet been reported. The prevention of inadvertent intravascular injection is of much greater importance than treatment of such a potentially devastating complication.
A negative aspiration test may falsely reassure the operator. The use of a nerve stimulator does not exclude the risk of accidental intravascular injection. The value of adding epinephrine to serve as an indicator of accidental intravascular injection represents an interesting debate. On the one hand, the addition of epinephrine to the local anesthetic solution can provide an early indication of intravascular injection. On the other hand, the addition of epinephrine may add confusion as to the cause of the block failure and delay definitive therapy. The importance of dose fractionation has been emphasised, because it provides an early warning system and an opportunity to terminate the local anesthetic injection at the first sign of toxicity. Slower injection of local anesthetic decreases the maximal blood concentration. Prolonging the duration of an intravenous bolus of levobupivacaine from one to three minutes in sheep has been shown to reduce the peak plasma concentration by about 40%. Nonetheless, whereas good technique will reduce the risk of toxicity it will not preclude it.

It should not be necessary to remind anaesthesiologists of the basic safety requirements (monitoring, resuscitation equipment and drugs – the latter including lipid emulsions) that should be available when performing regional blocks. Nonetheless, we suspect that in most developing countries, many – if not most – regional blocks using bupivacaine are performed by orthopaedic surgeons and general practitioners. They would represent an important target audience for education on lipid rescue.

Conclusion
Corcoran and colleagues have reported that the incidence of local anaesthetic toxicity (7.5 to 20 per 10 000 peripheral nerve blocks and 4 per 10 000 epidurals) is declining, even as total number of blocks is increasing. While this may indicate a greater adherence to basic safety requirements (monitoring, resuscitation equipment and drugs – the latter including lipid emulsions) that should be available when performing regional blocks. Nonetheless, we suspect that in most developing countries, many – if not most – regional blocks using bupivacaine are performed by orthopaedic surgeons and general practitioners. They would represent an important target audience for education on lipid rescue.

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