Hypertriglyceridaemia: an update
Anthony S Wierzbicki 1, Eun Ji Kim, Oluwayemisi Esan, Radha Ramachandran2

ABSTRACT
Triglycerides (TGs) form part of the standard lipid profile. Elevations in TGs are associated with increased cardiovascular disease risk through triglyceride-rich lipoprotein particles found as part of non-HDL cholesterol. Many elevations of TGs are secondary to other causes, but primary hypertriglyceridaemia syndromes need to be identified. The genetic causes of hypertriglyceridaemia range from familial combined hyperlipidaemia through the autosomal recessive remnant hyperlipidaemia (related to apolipoprotein E variants) and familial chylomicronaemia syndromes. Patients with primary hypertriglyceridaemia >10 mmol/L require characterisation and specific intervention. Simple lipid profiles do not provide adequate information for detailed diagnosis and additional assays such as apolipoprotein (apo)B100 apoE genotype and next-generation sequencing may be useful. Management of raised TGs includes optimising diet, reducing exacerbating factors as well as lipid-lowering medications such as statins, fibrates, niacin and omega-3 fatty acids. Novel medications for orphan disease indications such as familial chylomicronaemia syndrome include volanesorsen, evinacumab and other antisense therapeutics. Extreme hypertriglyceridaemia syndromes, especially chylomicronaemia syndromes, which can be exposed by pregnancy or other factors are a medical emergency and require admission and specialist management sometimes including plasma exchange.

INTRODUCTION
Triglycerides (TGs) show a complex relationship with glucose metabolism and CVD and are affected by processes, which control energy metabolism. The epidemiology, investigation and management of patients with raised TGs have moved on since this topic was last reviewed in 2009. This article presents a short update on these topics.

METABOLISM OF TRIGLYCERIDE-RICH LIPOPROTEINS
Biologically, TGs are the main energy source for metabolism and are stored in adipose tissue. A detailed discussion is beyond the scope of this article, but reviews exist on liver, muscle and general metabolism of triglycerides.2 4 Triglycerides are synthesised by enterocytes in the gut postprandially (exogenous pathway) and by hepatocytes in the liver (endogenous pathway)5 (online supplementary figure I). Enterocytes secrete chylomicron (CM) particles containing a short form (48%) of apolipoprotein (apo) B (apoB48), while hepatocytes secrete very low-density lipoprotein (VLDL) with full length apoB (apoB100). Secretion of hepatic triglyceride-rich lipoproteins (TGRL) is complex as hepatocytes secrete 2 forms of VLDL, which are metabolised differently.2 6 These particles can be further modified to form atherogenic small dense particles.7

DEFINITION OF HYPERTRIGLYCERIDAEMIA
Hypertriglyceridaemia is categorised using the National Cholesterol Education Program consensus with TG > 2.3 mmol/L (200 mg/dL) defined as abnormal (table 1).8 The stricter criterion of > 1.7 mmol/L (150 mg/dL) was introduced based on the detection of small dense LDL in Caucasian patients. Elevated TGs are found in 30% of individuals and prevalence increases with age.9 This definition was based on consensus and does not map easily onto centiles of the triglyceride distribution. In the community, the 99th centile is TG > 5.7 mmol/L in men and > 3.7 mmol/L in women10 and elevated TGs are common in lipid clinics.9 11

EPIDEMIOLOGY OF TRIGLYCERIDES
The relationship of TG with CVD risk has proved difficult to establish given the inverse relationship between TG and high-density lipoprotein cholesterol (HDL-C). The lower variance in HDL-C compared with TG leads to HDL-C being prioritised for CVD risk calculators. The Munster Heart Study (PROCAM)12 and other cohorts13 identified TG as a CVD risk factor after correcting for HDL-C. Meta-analyses have confirmed the relationship between TG and CVD risk.14 15 The clearest relationship with CVD is seen with the cholesterol content of TGRL and other particles—non-HDL-C (the difference between total cholesterol and HDL-C).15 Non-HDL-C shows greater predictive capacity than LDL-C and correlates strongly with apoB or particle number.16 17 Many CVD guidelines have adopted non-HDL-C18–20 as a secondary target after LDL-C while some also add apoB levels as a further criterion.19 21 While current treatment strategies focus on optimising LDL-C levels, the role of TGs in identifying excess residual risk is increasingly recognised.2 5 22 23

High TGs, reduced HDL-C and atherogenic sLDL (the atherogenic triad) form part of the metabolic insulin resistance syndrome (M-IRS).5 7 This is defined as (population-specific)26 central obesity, allied with 2 from 4 of raised TG (> 1.7 mmol/L), reduced HDL-C (< 1.0 mmol/L), hypertension and dysglycaemia.23 The number of M-IRS risk factors shows an approximately linear association with CVD while some also add apoB levels as a further criterion.19 21 While current treatment strategies focus on optimising LDL-C levels, the role of TGs in identifying excess residual risk is increasingly recognised.2 5 22 23

Elevated TG levels are also associated with increased risk of pancreatitis. The relative risk compared with TG < 1.0 mmol/L is 2.9 (95% CI 1.6 to 5.7)-fold at 3–4 mmol/L25 increasing to 360-fold in patients with TG > 20 mmol/L and
chylomicronemia syndromes. There is a case for characterising and treating any patient with TG >10 mmol/L by analogy to severe hypercholesterolaemia with cholesterol >9 mmol/L. Most hospital admissions seem to occur with TG >3.5 mmol/L, but interactions occur between TGs, inflammation and other factors.

TRIGLYCERIDE-RELATED LABORATORY TECHNIQUES

Triglycerides can be measured in fasting and postprandial states. Usually, these two measures are well correlated and 8–12-hour fasting is not required except in severe cases or when insulin resistance/diabetes is present. The standard assays measure glycerol released after hydrolysis of triglycerides. Patients with some inherited errors of glycolysis or those receiving intravenous fat emulsions, which contain glycerol can have pseudo-hypertriglyceridaemia. While TGs are usually measured in plasma or serum, they can be used in the diagnosis of chylothorax either by a significant discrepancy of lipids and apoB from plasma levels or by TG >1 mmol/L with cholesterol <5 mmol/L. Combinations of lipids and apoB levels are used in the diagnosis of familial chylomicronaemia syndrome (FCS) (ie, TG >10 mmol/L; TG/cholesterol ratio >2.2 (in mmol/L) and apoB <1 g/L) and to identify patients likely to have apoE variants. Automated analysers also detect CM particles through the lipaemia index and ideally all specimens with a high lipaemic index should have TG measured. Elevated indices indicate TG interference with some assays e.g. plasma sodium or liver transaminases.

A detailed discussion of analytical methods is beyond the scope of this article, but details of assays can be found in reference texts. The reference methods of lipid centrifugation identify CM and VLDL fractions as well as LDL and report TG or cholesterol contents. These may be superseded by fast protein liquid chromatography as problems with recovery of 'sticky' CMs occur with centrifuge assays exist. Similarly, antibody-based techniques for quantitation of apolipoproteins within TGRLs or other particles may be superseded by ultraperformance liquid chromatography mass spectrometry methods.

Lipid electrophoresis can distinguish CM (origin band), VLDL (pre-beta) and LDL (beta) fractions (online supplemental figure 2) but is a dated slow assay. Its conclusions can be achieved more speedily using automated profiles (lipids and apoB) which can be interpreted using an algorithm (online supplemental figure 3). Assays for apoB<sub>40</sub> distinguish VLDL from CMs while apoB<sub>38</sub> is used in research as it is not standardised.

More detailed profiles of TGRLs and their subfractions can be obtained using gradient ultracentrifugation techniques, size separation through graduated gels or by magnetic resonance profiling of lipid particles. They are mostly used in research as they add little to standard profiles and show poor intermethod agreement. Genetic techniques and triglycerides

Genetic techniques have long been used in the investigation of lipid disorders, but few have made the transition from research to the laboratory except in rare disorders. Specific genetic panels are used to identify patients with chylomicronaemia syndromes (see below) and polygenic risk score panels have been devised but not yet widely adopted. The most common genetic marker used in lipid clinics identifies common coding single nucleotide polymorphisms in the apolipoprotein E (apoE) gene, which result in altered amino acid charges. Different isoforms can be separated on ampholyte isoelectric focusing gels (phenotyping) or identified by genetic techniques. ApoE acts a marker of macrophage function and apoE deficient mice are a long-established model of atherosclerosis. Homozygosity for apoE2 in remnant hyperlipidaemia (familial dyslipoproteinaemia; Fredrickson type 3) is associated with excess intermediate density lipoprotein (IDL), remnant hyperlipidaemia, reduced LDL-C (online supplemental figure 4). Many individuals with apoE2/E2 do not develop lipid abnormalities or CVD so secondary genetic or environmental factor are likely to be necessary. Homozygosity for apoE2 allied with remnant hyperlipidaemia is associated with an 8–9-fold increased risk of CVD. Large epidemiological studies show no clear association with CVD for apoE but a dose proportional association for apoE4 with an 8%–12% excess risk per allele (figure 1). However, apoE4

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Table 1 Definitions of hypertriglyceridaemia in National Cholesterol Education Program correlated against Fredrickson-defined hyperlipidaemia class, predominant lipoprotein fractions and approximate prevalence in the National Health and Nutrition Examination Study (NHANES) and Very Large Database of Lipids study of specialised lipid sample requests

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition (mmol/L; mg/dL)</th>
<th>Fredrickson class</th>
<th>Prevalence in general population (%)</th>
<th>Prevalence in lipid clinic (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt;1.7 (150)</td>
<td>2A LDL</td>
<td>67</td>
<td>59.9</td>
</tr>
<tr>
<td>Borderline</td>
<td>1.7–2.2 (150–200)</td>
<td>2A LDL</td>
<td>15</td>
<td>3.9</td>
</tr>
<tr>
<td>Raised</td>
<td>2.3–5.5 (200–500)</td>
<td>2B LDL&gt; VLDL</td>
<td>16.5</td>
<td>10.3</td>
</tr>
<tr>
<td>High</td>
<td>5.6–10.9 (500–1000)</td>
<td>3 or 4 IDL and VLDL</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Severe</td>
<td>11.0–19.9 (1000–1800)</td>
<td>4 Excess VLDL</td>
<td>24.1</td>
<td></td>
</tr>
<tr>
<td>Extreme</td>
<td>&gt;20–22 (&gt;1800–2000)</td>
<td>5 VLDL and CM</td>
<td>NA</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>&gt;20–22 (&gt;1800–2000)</td>
<td>1 CM and CM remnants</td>
<td>1 in 10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>NA</td>
</tr>
</tbody>
</table>

CM, chylomicron; IDL, intermediate density lipoprotein; LDL, low-density lipoprotein; VLDL, very low-density lipoprotein.

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Figure 1 Relative risk of cardiovascular disease (CVD) events associated with different apolipoprotein E genotypes. Data provided for genotypes with 95% CIs. Data from Bennet et al.

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also associates with the function of brain-associated macrophage lineage cells (microglia) and a dose proportional risk (heterozygote OR 4–6; homozygote OR 8–12) for Alzheimer’s disease.\textsuperscript{58} This translates to an earlier onset of disease of 2.5 years per apoE4 allele. However, apoE4 shows only a sensitivity of 57% and specificity of 67% for Alzheimer’s disease.\textsuperscript{58}

**Influence of TGs on calculating LDL-C**

Most laboratories do not measure LDL-C but calculate its level using the Friedewald equation.\textsuperscript{36,39} This method assumes a fixed TG proportion in TGRLs (ie, divide TG by 2.2 (mmol/L) or by 5 (mg/dL) and so requires fasting samples (ideally >12 hours). It shows negative bias in reporting LDL-C with TG >2.0 mmol/L becoming severe at TG >4.5 mmol/L,\textsuperscript{45} which is increased with aggressive lipid-lowering therapies as these change the relative loading of TGs and cholesterol in TGRLs.\textsuperscript{60} Quantification of LDL-C can be improved using direct LDL assays, but these are not reliably free of interference by TGRLs.\textsuperscript{62} Improved methods of calculating LDL-C in fasting samples have been derived\textsuperscript{45} either as tables\textsuperscript{63} or in a new equation valid up to TG of 8 mmol/L but remain to be fully validated in populations with rare dyslipidaemias or on lipid-lowering therapies.\textsuperscript{62}

\[ \text{LDL-C} = \frac{\text{TC} - \text{HDL-C} - \text{TG}/2}{0.972} - ((\text{TG}/8.26) + \text{TG}xN) \]

**Clinical Aspects of Hypertriglyceridaemia**

**Physical and pathological signs**

The skin is a major organ for lipid metabolism.\textsuperscript{63} Severe hypertriglyceridaemia is associated with deposition of lipids in the skin.\textsuperscript{64} These occur commonly in the thin skin around the eyelids as xanthelasma. Deposits in the dermis visible in skin creases, for example, palmar striae are typical of remnant hyperlipidaemias. Severe cases result in epidermal as well as dermal lipid deposition—tuberose xanthomata on the knees, elbows and occasionally palms. Greater levels of TGs and VLDL are associated with epidermal TG and cholesterol deposition especially on the abdomen, elbows, knees and pressure points (Koebner phenomenon). Eruptive xanthomata are filled with yellow lipid deposits but fade to pink as they resolve.

**Primary versus secondary hypertriglyceridaemia**

A distinction is made between primary and secondary hypertriglyceridaemias. The common secondary causes are poorly controlled diabetes, excess alcoholic consumption and various medications or endocrine disease (table 2). Many cases arise from interaction of genetic factors with environmental and secondary causes such as non-alcoholic fatty liver disease. Secondary causes need treatment alongside lipid-lowering therapies. Lipodystrophy or mitochondrial myopathies require disease-specific management and some lipid-lowering therapies may not be appropriate.\textsuperscript{64}

**Genetic Lipid Syndromes**

A number of genetic aetiologies are associated with hypertriglyceridaemia\textsuperscript{66} ranging from common disorders such as familial combined hyperlipidaemia (FCHL), uncommon such as remnant hyperlipidaemia or rare ones such as monogenic dyslipidaemias.\textsuperscript{67}

**Familial combined hyperlipidaemia**

FCHL has a frequency of 0.48%–11.4% depending on the criteria used.\textsuperscript{68} It may show an ‘autosomal dominant’ pattern inheritance but is actually caused by polygenic inheritance of a group of genes exacerbated by environmentally determined factors leading to a variable lipid profile and often premature CVD.\textsuperscript{69,70} The diagnosis is based on the lipid profile, family history and exclusion of secondary causes though diagnostic nomograms based on TG and apoB have been proposed in some populations.\textsuperscript{71} Unlike familial hypercholesterolaemia (FH), FCHL is not a classical genetic disorder of coding proteins. It is most probably caused by an adiposopathy characterised by poor adipocyte retention of TGs and enhanced release of free fatty acids.\textsuperscript{72,73} The phenotype is exacerbated by the lipid genes located on chromosome 11 and those associated with endoplasmic reticulum VLDL handling (eg, uncoupling stimulating factor-1).\textsuperscript{74} This hyperlipidaemia is often treated with fibrate-statin combination therapy though no specific trials exist for this indication.

**Remnant hyperlipidaemia**

Remnant hyperlipidaemias are associated with polymorphisms in apoE.\textsuperscript{75} Homozygosity for apoE2 (familial dysbetalipoproteinaemia) leads to reduced clearance of LDL by the apoE-binding domain of the LDL receptor. Only 1% of individuals carrying apoE2/E2 develop remnant hyperlipidaemia suggesting an interaction with environmental or (as yet uncharacterized) genetic factors as apoE2 explains 35% of the variance.\textsuperscript{78} It is associated with 7–9-fold excess of CVD distributed across all vascular beds.\textsuperscript{13} Dermal skin crease lipid deposits may be

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Principal causes of secondary hypertriglyceridaemia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lifestyle factors</strong></td>
<td><strong>Principal diseases</strong></td>
</tr>
<tr>
<td>Pregnancy (physiological in third trimester)</td>
<td>Diabetes (uncontrolled)</td>
</tr>
<tr>
<td>Alcohol excess</td>
<td>Insulin resistance/obesity</td>
</tr>
<tr>
<td>Carbohydrate excess</td>
<td>Chronic renal failure</td>
</tr>
<tr>
<td>Glucose-containing drinks</td>
<td>Cushion’s syndrome</td>
</tr>
<tr>
<td>Caffeine excess</td>
<td>Growth hormone deficiency</td>
</tr>
<tr>
<td>Adrenergic drugs of abuse</td>
<td>Lipodystrophy</td>
</tr>
<tr>
<td>Adrenergic drugs of abuse</td>
<td>Metabolic disease and mitochondrial myopathy</td>
</tr>
<tr>
<td>Adrenergic drugs of abuse</td>
<td>Glycogen storage disease</td>
</tr>
<tr>
<td>Adrenergic drugs of abuse</td>
<td>Bone marrow disease (paraproteinaemia)</td>
</tr>
<tr>
<td>Adrenergic drugs of abuse</td>
<td>Infection/extreme inflammation for example, pancreatitis</td>
</tr>
<tr>
<td>Adrenergic drugs of abuse</td>
<td>Systemic lupus erythematosus</td>
</tr>
</tbody>
</table>

Many of these causes interact with polygenic risk factors for hypertriglyceridaemia in susceptible individuals.
visible and in extreme cases planar palmar xanthomata develop. ApoE genotype or phenotype assays are specialist tests so algorithms to improve clinical diagnosis or to guide requesting exist (figure 2). This hyperlipidaemia is commonly treated with fibrate–statin combination therapy to enhance clearance of LDL though no specific trials exist for this indication.

Familial chylomicronaemia syndrome
FCS is a rare cause of severe TG elevation with a frequency of 1 in 1 000 000. It is caused by homozygosity in loss of function of genes associated with the lipolytic pathway—specifically LPL and its controlling cofactors (apoC2; apoA5); lipid maturation factor-1 and a cell surface receptor for LPL adducted to CM or VLDL—glycosyl-phospho-inositol-HDL-binding protein-1 (GPIHBP1). Persistence of CM in the general circulation is associated with free fatty acid toxicity and allied with their pro-inflammatory properties promotes pancreatitis.

In contrast, VLDL particles seem to have a lower inflammatory potential, so many patients with FCS have TG in the range 5–30 mmol/L while extreme TG levels >50 mmol/L are more typical of patients with excess VLDL. The risk of pancreatitis is associated exponentially with TGs but the threshold for presentation with pancreatitis seems to be 35 mmol/L. A consensus statement has suggested a scoring system for diagnosis of FCS, which can be used to guide genetic testing (table 3).

A monogenic cause has been found in 75% of patients with clinical presentations of FCS, but 25% of identical severe phenotype seems to have a polygenic cause.

Multigenic chylomicronaemia syndrome
A spectrum of severity exists in chylomicronaemia syndromes ranging from polygenic through rare variants to monogenic FCS. Patients with severe recurrent disease or extreme TG levels more commonly have monogenic causes, but polygenic causes occur in many cases and predominate at lower degrees of severity and hypertriglyceridaemia. In epidemiological studies of patients with high TG levels with multifactorial chylomicronaemia syndrome (MCS), heterozygosity for rare pathogenic variants is associated with a more severe phenotype than polygenic disease. Polygenic risk scores for high TGs for have been proposed but have not been widely validated. These effects are exacerbated not only by environmental risk factors, such as viral infections, smoking, gallstones or alcohol, but also by diabetes and autoimmune syndromes (IgG4 disease) or genes directly associated with pancreatitis. Polymorphisms also interact with environmental factors, for example, a carbohydrate responsive element binding protein polymorphism interacts with sugary drink consumption affecting TG levels.

Severe TG syndromes are commonly associated with pancreatitis rather than CVD events but apoA5 variants are independently associated with CVD. A small proportion of chylomicronaemia syndromes has an autoimmune cause with antibodies to LPL pathway proteins (including GPIHBP1, apoA5 and apoC2), and these may merit treatment with immune modulating drugs such as rituximab if such autoantibodies are found.

TREATMENT OF HYPERTRIGLYCERIDAEMIA
Dietary interventions
High-fat diets increase postprandial triglycerides, including both CMs and VLDL, but most VLDL-TG is derived from adipose tissue fatty acid recycling, and the major effects are mediated by insulin action in the liver. As the production of TGs is related to dietary factors, the amount of calories, carbohydrate and their glycaemic index will affect TG levels, modify HbA1c and weight. Alcohol contributes to higher TGs both through its actions in contributing free fatty acid precursors, action on cholesterol ester transfer protein and possibly by inhibiting LPL. Catecholamines regulate lipolysis. Epinephrine analogues including cocaine or amphetamines have significant effects on TG levels. A non-linear effect in normotriglyceridaemic individuals is seen with coffee with a reduction switching from (green) tea as lower TG levels are found.
individuals, MCT oil use reduces TG by 10%, but case reports in chylomicronaemia show up to 90% reductions. Insulin resistance and metabolic syndrome

Insulin resistance is associated with changes in lipid profiles and excess peripheral lipolysis due to the reduced sensitivity of adipose tissue to insulin with increased free fatty acid flux to the liver leading to VLDL synthesis and lipogenesis causing a fatty liver and excess plasma VLDL and TGRLs. Treatment of insulin resistance can reduce TGs by 10%–25%. Weight loss is key to improving the metabolic syndrome. Among drug therapies, metformin, pioglitazone, glucagon-like peptide 1 (GLP1) agonists or dipeptidyl peptidase-4 inhibitors (which prevent GLP1 degradation) have all been shown to improve NAFLD, insulin resistance and in many cases TG levels. However, GLP-1 agonist therapies are associated with an increase in risk of pancreatitis and so have to be used with caution in patients with severe hypertriglyceridaemia.

Statins

Statins inhibit 2-hydroxymethylglutarate-CoA reductase causing upregulation of hepatocyte LDL receptors. The LDL receptor can clear TGRLs through binding apoE and LDL by binding apoB100. Statins reduce TGs in proportion to baseline TG levels and to the LDL-lowering potency and dose of the statin. They are first-line drugs in the treatment of CVD and reduce CVD events by 21% per 1 mmol/L LDL-C reduction. Statins have anti-inflammatory actions through inhibition of isoprenoid synthesis and reduced the incidence of pancreatitis in clinical trials in a post hoc analysis of patients with limited, if any, hypertriglyceridaemia.

Fibrates and peroxisomal proliferator activator receptor agonists

Fibrates are peroxisomal proliferator activator receptor-alpha (PPAR-α) agonists. This nuclear receptor gene family can function as homodimers or heterodimers with the retinoid-X receptor (online supplemental figure 5). This network of receptors with (likely) fatty acid derived ligands can modulate lipids (PPAR-α), glucose (PPAR-γ), bile acids (farnesoid-X receptor) and inflammation (glucocorticoids). Drugs tend to be selective and not specific for receptor subsets in this network. Fibrates increase synthesis of LPL, inhibit apoC3 (an inhibitor of selective and not specific for receptor subsets in this network. Fibrates reduce TGs in proportion to baseline TG levels and to the LDL-lowering potency and dose of the statin. They are first-line drugs in the treatment of CVD and reduce CVD events by 21% per 1 mmol/L LDL-C reduction. Statins have anti-inflammatory actions through inhibition of isoprenoid synthesis and reduced the incidence of pancreatitis in clinical trials in a post hoc analysis of patients with limited, if any, hypertriglyceridaemia.

Omega-3 fatty acids

Omega-3 fatty acids reduce TGs related to dose and baseline TG levels with a maximum reduction of 40% at TG=8 mmol/L by reducing production rates of CM and VLDL mediated by the free fatty acid receptor-4 and have anti-inflammatory actions. At low doses, their effects on CVD outcomes are minimal, but higher doses, particularly of eicosapentaenoic acid (EPA), seem to be associated with lipid-independent effects in reducing CVD events. High doses of EPA are associated with reductions in CVD events but increase rates of atrial fibrillation and gastrointestinal adverse events. High dose mixed omega-3 fatty acids may exacerbate hypertriglyceridaemia in extreme cases (eg, chylomicronaemia) but may be used in special circumstances (eg, pregnancy) (see below).

Orphan indication drugs

A number of orphan indication medications have been developed for use in FCS. Initially, drugs targeting CM and VLDL synthesis were considered. One patient with FCS was treated with lomitapide, a microsomal transfer protein inhibitor, for 13 years with a reduction in TGs and pancreatitis but later developed hepatic fibrosis. Newer therapies target improving clearance of TGRLs by increasing the apoE/apoC3 ratio by inhibiting apoC3 or by targeting other modulators of the LPL pathway such as angiopoetin-like peptides. Volanesorsen, an antisense oligonucleotide (ASO) apoC3 inhibitor, reduces TGs by 70%–80%. Postlicensing registry studies suggest a 30%–50% reduction in pancreatitis events and admissions in FCS based on secondary (safety) endpoints. This ASO is associated with injection site reactions and thrombocytopenia. Regular platelet monitoring is required and most cases of thrombocytopenia are treated with dose interruption. Newer formulations in development such as ApoC3LRx based on N-acetyl galactosamine (Gal-NAc) modified ASO technology seem to have less adverse effects. An alternative strategy is to target ANGPTL3 either though an antibody (evinacumab) or using ASO or siRNA technologies. Early studies suggest that this is more effective in MCS than FCS unlike volanesorsen, which seems equally effective in both. Other approaches rely on upregulating apoC2 function—an activator of LPL.

Novel medications

Gene therapy has been investigated in patients with FCS. Alipogene tiparvovec, an adeno-associated virus-1 vector containing an increased function variant LPL 5447X, transiently decreased TGs but reduced pancreatitis events by 30%–50% by reducing CM production. It was discontinued for commercial reasons. New therapies in development include further trials of derivatives of EPA, a new more PPAR-α-specific fibrate- pemafibrate, which does not seem to affect creatinine metabolism, and a ANGPTL3 inhibitor—vupanosen. The high TG/low HDL-C subgroup in the Action to Control Cardiovascular Risk in Diabetes trial showed benefit of adding fenofibrate to statin therapy on CVD outcomes in patients with type 2 diabetes (T2DM) in contrast to the overall results, which have discouraged the use of nicotinamide is not essential to its activity. Its adverse effects include severe facial flushing mediated by prostaglandin (PG) D2 and PGE2 but also causes significant dysglycaemia. Niacin reduces TGs to a similar extent to fibrates and reduces CVD events in monotherapy but does not add to statins in combination therapy. Its use is now not recommended in many guidelines.
of combination therapy.\textsuperscript{134} However, recently the Pemafibrate to Reduce Cardiovascular OutcoMes by Reducing Triglycerides IN patiENs With diabeteS (PROMEnT) trial\textsuperscript{135} in secondary prevention or high-risk individuals with T2DM with residual dyslipidaemia (high TG; low HDL-C) was discontinued due to futility for CVD endpoints though combination therapy was safe. The development of vapanorsen was discontinued despite efficacy in reducing triglycerides.\textsuperscript{136,137}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{A scheme to manage acute pancreatitis induced by hypertriglyceridaemia. AKI, acute kidney injury; CRP, C-reactive protein; TG, triglyceride.}
\end{figure}

**Triglyceride emergencies**

Extreme hypertriglyceridaemia is a medical emergency.\textsuperscript{138,139} The risk of pancreatitis increases up to 200-fold at TG $>$10 mmol/L.\textsuperscript{28} In clinical practice, most admissions for TG-associated pancreatitis seem to occur with TG $>$35 mmol/L.\textsuperscript{140} Admissions are precipitated by infections (often viral), gallstones or alcohol intake and only 5\%–10\% are due to hypertriglyceridaemia alone.\textsuperscript{140,141} On admission patients need to be assessed through standard pancreatitis protocols and managed nil-by-mouth with fluids and pain relief (\textbf{figure 3}).\textsuperscript{138,139,142,143} Fasting TGs halve approximately every 24–48 hours and TG $<$5.56 mmol/L (500 mg/dL) is often used to define resolution.\textsuperscript{144} Insulin therapy (allied with heparin) is used to manage TGs with hyperglycaemia in patients with diabetes.\textsuperscript{139} Supportive management allied to fasting is superior to combined insulin-dextrose therapy.\textsuperscript{139,144} If TGs do not fall at the predicted rate, then plasma exchange or plasmapheresis may be used to reduce TGs by 60\%–65\%.\textsuperscript{139,143} In a series of five observational studies totaling 59 patients with FCS where 10\% died, plasma exchange was associated with a 77\%–100\% complete recovery rate.\textsuperscript{144} Plasma exchange or plasmapheresis are more frequently required if patients are on extracorporeal membrane oxygenation as CMs and large TG block the oxygenation membrane.\textsuperscript{144} Apheresis is ineffective.

**Triglycerides and pregnancy**

A physiological increase in TGs occurs in the third trimester of pregnancy\textsuperscript{146} rising from 1.5 mmol/L to 4 mmol/L,\textsuperscript{147} especially in patients with gestational diabetes.\textsuperscript{148} Individuals with latent hypertriglyceridaemia may be uncovered by pregnancy and require management by specialist medical obstetricians allied with lipid specialists. Most drug therapies are contraindicated in pregnancy. Management consists of minimising TGs with dietary fat restriction (often less than 10 gm/day).\textsuperscript{149,150} Drug intervention with MCT oil and/or omega-3 fatty acids is suggested at TG $>$10 mmol/L.\textsuperscript{151} Any hyperglycaemia needs to be managed aggressively with metformin and, if necessary, insulin. Intermittent plasma exchange or plasmapheresis may be required to keep TG $<$20 mmol/L.\textsuperscript{151} Labour is usually induced at 35–36 weeks.

**CONCLUSION**

Hypertriglyceridaemia is a common finding that often confuses both primary and secondary care. Detailed investigations are available for raised TGs but are relatively underused. Analogous to cholesterol $>$9 mmol/L any primary hypertriglyceridaemia $>$10 mmol/L should be characterised and treated.\textsuperscript{152} Extreme hypertriglyceridaemia associated with pancreatitis and/or pregnancy is a lipid emergency and requires urgent secondary care management.

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**Competing interests** ASW is a site clinical investigator for clinical trials of drugs in management of familial chylomicronaemia syndrome and high triglycerides including Akcea (volanesorsen; apoC3LRx), Arrowhead (Aro-papoC3) and Regeneron (evinacumab).

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Best practice


Supplementary Figure 1
Supplementary Figure 2
Supplementary Figure 3
Supplementary Figure 4

Change in LDL-cholesterol relative to apoE3/E3

E2/E2 E2/E3 E3/E3 E4/E3 E4/E4
Supplementary Figure 5