Review article

Quantifying atherogenic lipoproteins for lipid-lowering strategies: Consensus-based recommendations from EAS and EFLM


- Lipoprotein(a)-cholesterol is part of measured or calculated LDL cholesterol and lipoprotein(a) should be measured at least once in all patients.
- LDL cholesterol is the primary target of lipid-lowering therapies.
- Total cholesterol, triglycerides, HDL cholesterol, LDL cholesterol, and calculated non-HDL cholesterol (=total – HDL cholesterol) constitute the primary lipid panel for estimating risk of atherosclerotic cardiovascular disease (ASCVD) and can be measured in the nonfasting state.
- LDL cholesterol is the primary target of lipid-lowering therapies.
- Lipoprotein(a)-cholesterol is part of measured or calculated LDL cholesterol and lipoprotein(a) should be measured at least once in all patients.

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1. Introduction

In the new era of very low LDL-cholesterol (LDLC) concentrations, achievable with more intensive and novel lipid-lowering therapies, increasing attention is being focused on the assessment of lipid-related residual risk of atherosclerotic cardiovascular disease (ASCVD) using additional biomarkers beyond LDLC [1].

An important prerequisite to address present and future challenges of ASCVD prevention is the harmonisation of serum lipid and lipoprotein profiles produced by established and emerging laboratory tests and techniques. To that end, the multidisciplinary consensus panel of the European Atherosclerosis Society (EAS) and the European Federation of Clinical Chemistry and Laboratory Medicine (EFLM) recently addressed present and future challenges in the laboratory diagnostics of atherogenic lipoproteins. Total cholesterol, triglycerides, HDL cholesterol, LDL cholesterol, and calculated non-HDL cholesterol (\(=\) total – HDL cholesterol) constitute the primary lipid panel for estimating risk of atherosclerotic cardiovascular disease (ASCVD) and can be measured in the nonfasting state. LDL cholesterol is the primary target of lipid-lowering therapies. For on-treatment follow-up, LDL cholesterol shall be measured or calculated by the same method to attenuate errors in treatment decisions due to marked between-method variations. Lipoprotein(a)-cholesterol is part of measured or calculated LDL cholesterol and shall be estimated at least once in all patients at risk of ASCVD, especially in those whose LDL cholesterol decline poorly upon statin treatment. Residual risk of ASCVD even under optimal LDL-lowering treatment should be also assessed by non-HDL cholesterol or apolipoprotein B, especially in patients with mild-to-moderate hypertriglyceridemia (2–10 mmol/L). Non-HDL cholesterol includes the assessment of remnant lipoprotein cholesterol and shall be reported in all standard lipid panels. Additional apolipoprotein B measurement can detect elevated LDL particle numbers often unidentified on the basis of LDL cholesterol alone. Reference intervals of lipids, lipoproteins, and apolipoproteins are reported for European men and women aged 20–100 years. However, laboratories shall flag abnormal lipid values with reference to therapeutic decision thresholds.

2. Which atherogenic lipoproteins should be measured?

2.1. LDL particles

Assessment of LDLC is a key component of the management of risk of ASCVD [4–6]. Circulating LDL particles are highly atherogenic and there is a direct, graded relationship between LDL cholesterol concentration and the incidence of ASCVD observed in randomized controlled trials, prospective epidemiological cohort studies, and Mendelian randomization studies [7,8].

Despite the overwhelming evidence that LDLC-targeted therapies effectively reduce ASCVD in the population, many individuals experience ASCVD-related events or progression of atherosclerosis despite not having elevated LDL or even concentrations < 1.8 mmol/L [9]. This residual risk indicates that a focus solely on the measurement of LDLC is not an optimal strategy for all patients, in part explained by accumulating evidence that the number of LDL particles (LDLP) measured by lipoprotein subfractionation techniques is more strongly causally related to ASCVD than the cholesterol content of the particles [9,10].

All LDL particles are atherogenic, but their concentration is not always reflected by LDLC measurement because the cholesterol content in the particles can vary widely between individuals according to the continuous remodeling of lipoproteins in blood [10]. Small lipid-depleted LDL subfractions contain less cholesterol than larger ones. They are typically predominant in patients with moderately elevated triglyceride (TG) concentrations or related conditions, such as diabetes and the metabolic syndrome, without necessarily having high LDLC concentration [11]. These compacted LDL particles are the products of exchange of cholesteryl esters with TG from larger, TG-rich very low-density lipoprotein (VLDL) particles (Fig. 1). Concomitantly, smaller high-density lipoprotein (HDL) particles are also formed in this pathway, as typically manifested in the atherogenic dyslipidemic triad involving hypertriglyceridemia, increased small dense LDL, and low HDL-cholesterol (HDL-cholesterol) concentration [11].

While earlier studies emphasized the atherogenicity of small LDL particles, it is now recognized that all LDL particles are atherogenic, regardless of size [10]. Thus, the primary focus of treatment should remain the reduction of the number (concentration) of LDL particles, without efforts to distinguish between large and small LDL subfractions [1]. Measurement of apolipoprotein B (apoB), the major protein component of LDL, or advanced measurement of LDLP (not yet widely available) can also be used to assess the number of LDL particles [10,12].

The total cholesterol (TC) to HDLC ratio has been proposed as a surrogate marker of the number of LDL particles – associated with low HDLC and hence higher TC/HDL ratio in individuals with atherogenic dyslipidemia [10]. The TC/HDL ratio may be considered as an alternative to LDLP for risk estimation, but not for diagnosis or as therapeutic decision limit because a low ratio due to high HDLC can be misleading: this may lead to assuming a low risk even if the patient has high LDLC. The components of the ratio, TC and HDLC, have to be managed separately.
2.2. Remnant particles

Postprandial accumulation of TG-rich remnant particles in blood is an important factor in atherogenesis [13,14]. These lipoproteins contain a higher load of cholesterol that is not accounted for in typical fasting lipid profiles. Nonfasting lipid profiles, therefore, can potentially be more relevant to the estimation of an individual's cardiovascular risk than fasting lipids since in real life the postprandial state predominates most of our 24-h cycle [15,16].

TG-rich chylomicrons secreted from the intestine, and VLDL secreted from the liver, are rapidly depleted of part of their TG content and acquire cholesteryl esters from HDL in the circulation (Fig. 1). These cholesteryl-enriched remnant particles may enter the arterial intima and contribute to atherosclerosis, whereas nascent chylomicrons and very large VLDL particles do not cross the endothelial layer [17]. Mendelian randomization studies suggest that life-long high serum concentrations of TG-rich lipoproteins or their remnants are causally associated with increased risk of ASCVD and all-cause mortality [17,18].

Direct "homogeneous" assays have been developed to specifically measure cholesterol in remnant particles (RemnantC) and some have revealed significant associations of RemnantC with ASCVD [19,20]. An alternative is to calculate RemnantC as TC – HDL(C) – LDL(C), because RemnantC corresponds to all cholesterol not found in LDL and HDL, that is, in all VLDL and intermediate-density lipoproteins (IDL). In the nonfasting state a relatively small amount of cholesterol can also be found in chylomicron remnants. Because both newly secreted chylomicrons and VLDL rapidly undergo lipolysis, any residual circulating chylomicrons and VLDL can be considered remnants (IDL). In the nonfasting state a relatively small amount of cholesterol can also be found in chylomicron remnants. Because both newly secreted chylomicrons and VLDL rapidly undergo lipolysis, any residual circulating chylomicrons and VLDL can be considered remnants (IDL). Direct LDL.C measurement should preferably be used in the calculation of RemnantC; otherwise RemnantC simply equals TG/2.2 (in mmol/L) when Friedewald-calculated LDL.C is used, i.e. TC – HDL.C – (TC – HDL.C – TG/2).2, and it does not add clinical information beyond TG concentration [1]; however, it focuses the attention on the cholesterol content of remnants rather than the TG content.

RemnantC also contributes to non-HDL(C) which is calculated as TC – HDL(C) [1]. This term is independent of the Friedewald term and therefore not correlated as tight with TG concentrations as calculated RemnantC, and thus represents an additional clinically valuable marker. RemnantC, measured or calculated, differs from non-HDL(C) in that non-HDL(C) contains RemnantC plus LDL.C and does not differentiate between these two causal risk factors [1]. Non-HDL(C) also includes the cholesterol of lipoprotein(a) [Lp(a)].

2.3. Lipoprotein(a) particles

Lp(a) is an LDL-like particle with one molecule of apoB to which an additional apolipoprotein, apo(a), is attached. This apolipoprotein shows considerable size polymorphism originating from a variable number of kringle IV type 2 (KIV-2) repeats of apo(a) [21,22]. This size polymorphism is the most important determinant of the hepatic production rate of Lp(a): serum Lp(a) concentrations and number of KIV-2 repeats are inversely correlated, which results in marked genetic variation of Lp(a) concentrations [21,22]. Elevated baseline and on-statin treatment Lp(a) concentration above the 80th percentile of the general population (50 mg/dL) is a strong genetic risk factor for cardiovascular disease independent of LDL.C [23,24]. This is recognized by the codes of International Classification of Diseases for elevated Lp(a) and family history of elevated Lp(a), introduced in response to the US National Heart, Lung, and Blood Institute recommendation [25]. High Lp(a) concentration through a correspondingly low number of KIV-2 repeats
are also associated with a higher risk of mortality in the general population [3].

One of the major differences between Lp(a) and LDL particles is that LDLs are effectively lowered by statins, whereas Lp(a) is typically resistant to this treatment [24]. In statin-treated patients the Lp(a)-associated risk for ASCVD becomes an even better predictor for residual risk as soon as the LDL-associated risk is decreased by statin therapy [24].

Although proprotein convertase subtilisin/kexin type 9 (PCSK9) inhibitors and other novel therapies reduce Lp(a) and may contribute to reduction in ASCVD [26,27], it is yet unknown whether Lp(a) lowering per se contributes to the clinical benefit of these novel therapies [25]. Although recent studies with PCSK9 inhibitors were not designed to target patients with high Lp(a) concentrations, they nevertheless revealed that patients with higher baseline Lp(a) concentration experienced greater absolute reductions in Lp(a) and tended to derive greater clinical benefit from PCSK9 inhibition [27,28]. Drugs on the horizon that specifically target Lp(a) with an Lp(a)-lowering potential of 80% and more will have to prove the benefit of an isolated lowering of Lp(a) on ASCVD outcomes [29].

Recommendation.

- Comprehensive testing of atherogenic lipoproteins should use a biomarker, or a panel of multiple markers, to assess the risk of ASCVD associated not only with LDL particles, but also remnant particles and, in selected cases, Lp(a) particles.
- Recommendations for selection of atherogenic lipoprotein tests in different clinical settings are summarized in Table 4.

3. What is the standard lipid profile?

The traditional lipid profile of TC, TG, HDLC, and LDLC remains the primary approach for diagnosis and ASCVD risk classification [30]. A cost-efficient approach is to employ measurements of three markers (TC, TG, HDLC) and from these calculate LDLC and non-HDLC. RemnantC can also be calculated if directly measured LDLC is used in the equation.

ApoB measurement is not usually part of the standard lipid profile and ASCVD risk estimation models. Monogenic disorders such as

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Concentration distribution of nonfasting lipids, lipoproteins, and apolipoproteins in 54,129 women in the Copenhagen General Population Study not on lipid-lowering therapy.</th>
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<tbody>
<tr>
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Nonfasting triglycerides (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDLC), and apolipoprotein B concentrations were measured by automated assays (Thermo Scientific Konelab, Vantaa, Finland). Low-density lipoprotein cholesterol (LDLC) was calculated by the Friedewald equation when TG were < 4 mmol/L and was measured directly (Konelab) when TG were ≥ 4 mmol/L. Non-HDL cholesterol was calculated as TC minus HDLC. Remnant cholesterol was calculated as TC minus LDLc minus HDLC. The first 5592 individuals included in the Copenhagen General Population Study had lipoprotein(a) total mass measured using a sensitive immunoturbidimetric assay from DiaSys (DiaSys Diagnostic Systems, Holzheim, Germany), while all remaining individuals in the study had lipoprotein(a) measurements done using the apolipoprotein(a) isomorph insensitive Denka Seiken assay (Denka Seiken, Tokyo, Japan) or the Roche second generation lipoprotein(a) assay developed by Denka Seiken (Roche Diagnostics, Rotkreuz, Switzerland) [3].
familial hypercholesterolemia (FH) can be easily recognized from the standard lipid panel without the need to measure apoB [31,32]. In patients with mild-to-moderate hypertriglyceridemia, defined as 2–10 mmol/L [33], elevated baseline and on-treatment apoB helps identify the atherogenic dyslipidemia related to remnant lipoproteins combined with small dense LDL particles that is not reflected by LDLC and non-HDLC.

Lp(a) measurement should be considered at least once in each adult person’s lifetime to identify those with high inherited Lp(a) concentrations, in particular among patients with premature ASCVD.

<table>
<thead>
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<th>Table 3</th>
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<td>Concentration distribution of nonfasting lipids, lipoproteins, and apolipoproteins in 42,126 men in the Copenhagen General Population Study not on lipid-lowering therapy. Laboratory measurements and calculations were performed as described in the footnote of Table 2 [3].</td>
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</table>

![Intravascular remodeling of lipoproteins contributing to the typical serum lipid profile of atherogenic dyslipidemia.](image)

Fig. 1. Intravascular remodeling of lipoproteins contributing to the typical serum lipid profile of atherogenic dyslipidemia.

TG-rich chylomicrons (CM) secreted from the intestine, and VLDL secreted from the liver, are remodeled in the circulation primarily through the actions of lipoprotein lipase (LPL), hepatic lipase (HL), and cholesteryl ester transfer protein (CETP). The hydrolysis of TG by LPL, leading to liberation of free fatty acids (FFA), and the acquisition of cholesteryl esters (CE) from HDL by CETP generates smaller, cholesterol-enriched remnant particles which are depleted of part of their TG content and contributes to increased RemnantC concentrations measured in serum. Higher VLDL output resulting from FFA flux to the liver activates CETP, which results in TG enrichment of HDL and LDL through increased exchange and transfer of TG and cholesteryl ester. These cholesterol-depleted, TG-enriched LDL and HDL particles are also modified by HL, producing smaller LDL and HDL and contributing to lower serum concentrations of LDLC and HDLC, respectively, as typically manifested in the serum lipid profile of a patient with atherogenic dyslipidemia – frequently accompanying insulin resistance and metabolic syndrome with increased FFA flux to the liver.
FH, with a family history of premature ASCVD and/or elevated Lp(a), or with recurrent ASCVD despite statin treatment [22]. Lp(a) measurement may also be considered in those with aortic valve stenosis. However, Lp(a) measurement should not be included in repeated lipid profile measurements within the same patient, as Lp(a) concentrations exhibit little variation over a lifetime. Exceptions from this rule are transition to menopause, pregnancy, oral contraceptive use, renal impairment, or when specific Lp(a)-lowering treatment is administered [21]. Lp(a) concentrations do not change in response to normal food intake and are minimally increased in inflammation, although the influence of acute illness or acute phase reactions on Lp(a) concentration is discussed controversially [34].

Recommendation.

- The ‘standard lipid profile’ used for cardiovascular risk prediction includes TC, TG, HDLC, LDLC, non-HDLC, and optionally – if directly measured LDLC is used – calculated RemnantC. A ‘minimal lipid profile’ including only TC and TG can be considered in countries where costs are a major issue such as developing countries [35].
- An ‘expanded lipid profile’ including Lp(a) or apolipoprotein should be used in selected cases (Table 4) [35]. ‘Advanced lipid profiles’ such as lipoprotein subclasses and apolipoprotein profiles have been introduced in some laboratories but their added value in a clinical setting still needs to be validated [1].

4. When to use fasting and nonfasting blood samples?

Fasting blood samples have previously been the standard for measuring TG, because the fasting state reduces variability of TG concentrations and allows for a slightly more standardized LDLC estimation with the Friedewald equation; however, a fasting sample does not capture the average atherogenic lipid profile seen in the patient over a 24-h period [16]. In consequence, extended (8–12 h) fasting is no longer routinely required for the determination of a lipid profile [2]. Findings from population studies showed that despite minor postprandial increases in TG and RemnantC, quantitative changes in other lipids, lipoproteins, and apolipoproteins appear to be negligible in response to the habitual meal intake for most individuals [2]. For patients, laboratories, and clinicians alike, nonfasting lipid profiles represent an operational simplification without significant negative implications for prognostic, diagnostic, and therapeutic options for ASCVD prevention [36]. Regardless, it may remain prudent to counsel the patients to avoid an extremely high-fat or fast-food meal (e.g. a burger, fries) in the preceding 12 h [37].

Nonfasting lipid profiles are now endorsed by several guidelines including those in Europe, the UK, Canada, Brazil, and the US [4–6,35,38]. Nonfasting and fasting measurements of the lipid profiles must be viewed as complementary and not mutually exclusive. Fasting is certainly not critical for first-time screening and general risk estimation, or to diagnose an isolated hypercholesterolemia such as FH or elevated Lp(a) without concomitant high TG [2]. Fasting is an option when nonfasting TG are ≥4.5 mmol/L, a concentration seen in ~3–5% of nonfasting individuals in the general population (Tables 2-3) [17], and for the phenotypic diagnosis or therapeutic follow-up of mixed dyslipidemia or isolated hypertriglyceridemia; however, this is not a requirement and a random nonfasting blood sample will still best capture the average TG concentration in a given patient. Fasting may also be recommended for starting medications that cause severe hypertriglyceridemia (e.g., isotretinoin) in genetically predisposed individuals, for patients recovering from hypertriglyceridemic pancreatitis, and when additional laboratory tests that require fasting or morning samples (e.g., fasting glucose, or markers with circadian rhythm) are requested [2]. The EFLM Preanalytical Phase Working Group recently produced guidance on how to standardize fasting blood sampling if needed [37,39].

Recommendation.

- Fasting is not routinely required for the determination of a lipid profile.
- In patients in whom an initial nonfasting lipid profile reveals a TG concentration ≥4.5 mmol/L, a repeat lipid profile in the fasting state could be performed to assess fasting TG concentration; however, this is not a requirement.

5. Are LDLC measurements or calculations reliable?

5.1. Operational definition of LDL

Beta-quantification, the US Centers of Disease Control (CDC) Reference Method for LDLC, combines ultracentrifugation to remove VLDL and chylomicrons and heparin-Mn2+ precipitation to separate LDL particles, including Lp(a), from HDL [40]. With beta-quantification, the lipoprotein fraction in the density range of 1.006–1.063 g/mL is defined as LDLC, and the fraction in the density range of 1.063–1.21 g/mL is defined as HDLC [40]. However, it is not widely recognized that the LDLC fraction on beta-quantification also contains the cholesterol from LDL with density 1.066–1.019 g/mL and Lp(a) with density 1.04–1.13 g/mL. LDLC assays that attempt to specifically measure cholesterol in LDL may, therefore, show discordant results compared to the reference method [41].

5.2. Direct LDLC and HDLC assays

The “homogeneous” or “direct” LDLC (dLDLC) and HDLC (dHDLC) assays have largely replaced the older ultracentrifugation and precipitation techniques, particularly for HDLC, but these measurements cannot be generally assumed to provide the same clinical information [40,41]. The total error of measurement combines systematic bias (deviation from “true” value) and random imprecision. Despite improved analytical precision due to automation, data indicate that results can vary significantly between dLDLC and dHDLC assays from different manufacturers [41]. Most discrepancies – with marked biases between assays and the CDC Reference Methods – are observed in samples from patients with hypertriglyceridemia > 2 mmol/L, mixed dyslipidemia, or other conditions involving altered lipoprotein composition and remodeling, such as diabetes and chronic kidney disease [41]. Direct measurements of dLDLC and dHDLC in normallipidemic samples usually meet the National Cholesterol Education Program (NCEP) total error goals of ≤12% and ≤13%, respectively, but total error ranged from −26% to +32% for dLDLC and −20% to +36% for dHDLC in a comprehensive study of different assays in dyslipidemic samples [42]. Most discordances in dyslipidemic samples are observed at lower concentration ranges of LDL (< 1.8 mmol/L) and HDLC (< 1.0 mmol/L) [42]. These errors result in misclassifications with respect to ASCVD risk assessment depending on the type of assay, as observed in accuracy-based external quality assessment surveys of hypertriglyceridemic samples organized across different laboratories [43]. The biases noted in dHDLC measurements affect the calculations of LDL and non-HDLC, since HDLC is used in the calculations [43].

The biases noted in dLDLC and dHDLC assays when analyzing dyslipidemic samples suggest that non-specific cross-reaction takes place, reflecting difficulties in selectively measuring the cholesterol in LDL or HDL fractions when atypical lipoproteins are present. The different manufacturers’ direct methods do not measure the same LDL and HDL subfractions [40,41]. This non-selectivity error is of major concern.
5.3. Calculated LDLC

LDLC calculated with the Friedewald formula, cLDLC = TC – HDLC – VLDL cholesterol (VLDLC), has its limitations. The equation uses a fixed TG:cholesterol ratio (TG/2.2 in mmol/L or TG/5 in mg/dL) to estimate VLDLC and assumes lack of chylomicrons which are more TG-rich than VLDLC [44]. Because the TG:cholesterol ratio in TG-rich lipoproteins progressively increases as hypertriglyceridemia becomes more severe, the equation overestimates VLDLC and therefore underestimates LDLC at high TG concentrations [44]. The equation is increasingly inaccurate at TG concentrations from 2.3 to 4.5 mmol/L [44]. The error is regarded as unacceptably large when TG are ≥4.5 mmol/L by NCEP and EAS guidelines or already at ≥4.0 mmol/L by national consensus in certain countries, and fasting blood samples should be used in this condition [2]. At TG < 4.5 mmol/L nonfasting and fasting lipid profiles can be used alike for Friedewald cLDLC, when LDLC is not very low.

At very low LDLC concentration ranges < 1.8 mmol/L, in which VLDLC constitutes a relatively larger fraction of the blood cholesterol, VLDLC overestimation at high TG concentration > 2.3 mmol/L introduces a more significant error in the calculation of cLDLC [45]. The resulting underestimation of LDL LC may translate to downward misclassification when using guideline-recommended 1.8 mmol/L or 1.4 mmol/L thresholds for patients at high and very high cardiovascular risk, respectively [4]. This may erroneously exclude >20% of patients for initiation or intensification of lipid-lowering therapy [45].

A modified equation, Martin-Hopkins cLDLC = TC – HDLC – TG/10, which adjusts the TG/VLDLC ratio dynamically for concentrations of TG and non-HDL-C has been developed [46]. Rather than dividing TG by a fixed factor of 5, the Martin-Hopkins equation requires the use of a 180-cell table to match each patient’s TG and non-HDL-C with 1 of 180 different factors ranging from 3.1 to 9.5, to give a more personalized estimation of VLDLC in mg/dL [46]. These personalized TG/VLDLC ratios were determined by direct comparison of TG to VLDLC concentrations directly measured after lipoprotein separation by ultracentrifugation in >10^6 US individuals from the Very Large Database of Lipids Study [46]. In this database, TG and non-HDL-C are the two variables that explained most of the variance in TG/VLDLC [46].

The novel Martin-Hopkins formula improves the accuracy of cLDLC at various conditions including very low LDL-C < 1.8 mmol/L and in nonfasting samples [47,48]. We recommend to use it preferably in the range of TG concentrations 2.0–4.5 mmol/L wherein the Friedewald equation is less accurate [47]. However, it is not trivial to install the complex 180-cell approach of this formula into automated laboratory information systems. A smartphone application (“LDL Cholesterol Calculator”) has been developed to provide immediate and automated calculation of Martin-Hopkins cLDLC by simple input of a patient’s TG, HDLC, and TG data from the standard lipid profile [49].

Direct LDLC assays should always be used when TG concentration is ≥ 4.5 mmol/L, which is the limit of use of Friedewald and Martin-Hopkins equations [50], although above this concentration the direct assays may also show discordances with the CDC Reference Method and will not necessarily result in accurate LDLC measurement in every patient. Even in normotriglyceridemic samples and in samples with moderately elevated TG concentrations 2.0–4.5 mmol/L, dLDLC may not always agree with Friedewald cLDLC and translate to discrepant risk classifications as observed in fasting as well as nonfasting individuals [51]. It should be noted that most clinical trials demonstrating the evidence base for clinical benefit of LDLC lowering have used Friedewald cLDLC; thus it cannot be excluded that dLDLC rather than cLDLC is the method that misclassifies risk [1]. However, the fact that cLDLC calculated by either Friedewald or Martin-Hopkins equation depends upon three laboratory assays, that is, TG, TC, and dHDL-C, means that three measurement errors are involved which inevitably introduce calculation variability (Table 5).

### Table 4

<table>
<thead>
<tr>
<th>ASCVD risk estimation</th>
<th>Dyslipidemia characterization</th>
<th>Treatment choice</th>
<th>Treatment target</th>
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<tr>
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<td>Optionalc</td>
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<td>NOj</td>
<td>Not yetj</td>
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- a In nonfasting samples this will also include cholesterol in chylomicrons and their remnants; however, in the majority of individuals chylomicrons are rapidly converted into remnants (within 5–10 min) after delivery from lymphs to the bloodstream.
- b To be considered in a minimal lipid profile (TC and TG only) or when LDLC is not available.
- c Or Apo-A-I if available.
- d In combination with TC, if HDLC is entered as a separate variable in the risk estimation model. Ratios of TC/HDL-C, non-HDL-C/HDL-C, or apoB/apoA-I which reflect the balance between atherogenic and neutral lipoproteins can be considered as an alternative for risk estimation, but not for diagnosis or as treatment targets. The components of the ratio have to be managed separately.
- e RemnantC, calculated as TC – HDLC – LDLC, is all cholesterol found in TG-rich lipoproteins VLDL, IDL, and, in the nonfasting state, additionally chylomicron remnants. RemnantC is included in non-HDL-C, but non-HDL-C does not differentiate between LDL-C and RemnantC. RemnantC is the part of non-HDL-C in addition to LDL-C that needs reduction in some patients. Directly measured LDL-C should preferably be used in the calculation of RemnantC, or RemnantC could be measured directly.
- f Non-HDL-C, calculated as TC – HDLC, is all cholesterol in atherogenic lipoproteins: LDL, remnants, and Lp(a). None of the hyperlipidemias can be characterized by non-HDL-C because the composite marker does not differentiate between the atherogenic lipoprotein-cholesterol fractions.
- g In patients with mild-to-moderate hypertriglyceridemia, 2–10 mmol/L (175–880 mg/dL), diabetes, obesity or metabolic syndrome.
- h Or advanced LDL-C measurement if available.
- i At least once in each adult person’s lifetime, especially in patients with premature ASCVD (men < 55 years, women < 60 years), family history of premature ASCVD and/or elevated Lp(a), FH, recurrent ASCVD despite optimal lipid-lowering treatment.
- j Unless approved treatment is available to substantially reduce Lp(a) concentration and Lp(a)-related risk.

in the contemporary treatment era in which very low LDL concentration ranges < 1.8 mmol/L are increasingly seen with highly efficacious LDL-lowering therapies, and in which hypertriglyceridemic samples – TG > 2 mmol/L seen in ~25% of individuals in the general population (Tables 2-3) [17] – cause a greater analytical problem due to the increasing prevalence of obesity, metabolic syndrome and diabetes mellitus [11].
with suspected high Lp(a), particularly in African-Americans, in patients with nephrotic syndrome, in those undergoing peritoneal dialysis, and in any patient who does not respond sufficiently to statin therapy [1]. If a high Lp(a) concentration is indeed the cause for an apparent non-response or low response of LDLC, then it might not be useful to increase the dosage of statin under such conditions [1]. The correction is as follows with Lp(a) values reported in mg/dL:

\[
\text{Lp(a)-corrected LDLC (mg/dL) = LDLC (mg/dL) – [Lp(a) (mg/dL) \times 0.30]}
\]

\[
\text{Lp(a)-corrected LDLC (mmol/L) = LDLC (mmol/L) – [Lp(a) (mg/dL) \times 0.0078]}
\]

At this point of time, we do not provide alternative formulas for Lp(a) reported in nmol/L (despite a proposed rough estimate of 2-2.5x conversion factor from mg/dL to nmol/L) [25]. It has to be recognized that a simple conversion of Lp(a) from mg/dL to nmol/L or vice versa has its limitations since probably most of the available immunoassays cannot measure Lp(a) in strict molar terms due to the size heterogeneity of apo(a) isoforms and the high probability that antibodies against apo(a) recognize a repetitive KIV-2 epitope of apo(a) [53].

Recommendation.

- The Martin-Hopkins modified equation may be preferable for calculation of cLDLC, most importantly in patients with low LDLC concentration < 1.8 mmol/L and/or TG concentrations 2.0–4.5 mmol/L, and in nonfasting samples [6].
- Direct LDLC assays should be used for calculation of RemnantC and for assessment of LDLC when TG concentration is ≥ 4.5 mmol/L (or ≥ 4.0 mmol/L by national consensus in certain countries). However, the direct assays will not necessarily result in more accurate LDLC assessment in every patient.
- Lp(a)-cholesterol correction of measured or calculated LDLC should be applied in patients with known or suspected high Lp(a) concentration, or if the patient shows a poor response to LDL-lowering therapy.

6. LDLC test errors: are they clinically relevant?

The ranges of uncertainty across different LDLC methods are not negligible (Table 5). Between-laboratory variation of a certain patient's measured or calculated LDLC can range widely over the guideline-driven critical values that determine the decision of therapeutic intervention (Table 6). Depending on the method used, different treatment decisions may be taken, or confusion may arise if the patient's samples for monitoring are sent to different laboratories using different methods or when a laboratory changes the method. Not uncommonly, changes in a patient's LDLC test result over time are within the range of uncertainty of laboratory method variation and may not be due to therapeutic intervention [1].

These issues are, however, less relevant for the monitoring of the patient by the same laboratory and method over time. In this situation, the non-specificity bias remains constant over time and only the assay imprecision (random error) and lot-to-lot variation are relevant, which may not be important given that clinicians are not aiming to achieve the LDLC targets exactly but often concentrations below it. In the present era, the percentage of LDLC reduction is more important than achieving specific targets, and indeed recent guidelines suggest that achievement of a > 50% reduction in high- and very high-risk patients is paramount irrespective of baseline LDLC concentration [4].

The risk that errors in LDLC measurement or calculation affect the clinical decision is further attenuated by the recommendation that decision to initiate a treatment, or adjusting or shifting to another treatment, should not be taken on one LDLC test, but rather after multiple repeated testing (at least two times) to allow averaging for intra-individual (biological) variation [41]. The EFLM Biological Variation Working Group recently revised biological variation data [54,55].

Recommendation.

- Follow-up of on-treatment lipid profiles in a patient should ideally be undertaken with the same method (and preferably in the same laboratory) to minimize misinterpretation of treatment effect.
- Clinicians should be notified by the laboratory when the test changes from one method to another, e.g. through newsletters. This will enhance clinicians' awareness of changes in methods as a potential cause of implausible test results.
- Assay methods and their limitations should always be described in any publication of clinical trials or epidemiological studies. In meta-analyses of associations of lipid tests with outcomes, it is critical to verify the comparability of quantitative data of the assays used in each trial.
- A patient's LDLC value close to therapeutic decision thresholds should ideally be confirmed by repeated measurement(s) (≥2) by the same method and then averaged. Often the repeated test value is lower due to improved diet after the first test if the patient is told that LDLC is elevated; in this case the second value should be accepted for decision making.

7. Are other measurements of atherogenic lipoproteins reliable?

7.1. Non-HDL cholesterol

Calculated by subtracting HDLC from TC, non-HDLc represents the cholesterol in all particles causing cardiovascular disease, that is, LDL, VLDL, IDL, and Lp(a); in the nonfasting state this additionally includes...
the cholesterol in chylomicrons and their remnant particles [1]. Non-HDLC provides a more comprehensive risk assessment than LDLC in certain individuals with hypertriglyceridemia because it adds RemnantC to LDLC and, therefore, takes into account the atherogenic potential of remnant lipoproteins [17]. However, non-HDLC cannot substitute for RemnantC because it does not differentiate between RemnantC and LDLC and Lp(a)-cholesterol. Some individuals with high RemnantC have low LDLC and thus will have relatively low non-HDLC if Lp(a) is also low, and if interpreting non-HDLC instead of RemnantC, the high RemnantC will be masked in these individuals [30].

Like LDLC, non-HDLC is treatable with existing lipid-lowering agents and there is a direct, consistent relationship between the magnitude of non-HDLC lowering and cardiovascular risk reduction observed in meta-analyses and trials with statins and other lipid-lowering agents [56,57]. Guideline-recommended therapeutic goals for non-HDLC are arbitrarily set typically at 0.8 mmol/L (30 mg/dL) higher than LDLC goals (Table 6); this value is based on the assumption that the “optimal” VLDLC concentration associated with the fasting TG threshold 1.7 mmol/L is 0.8 mmol/L, as estimated by the Friedewald formula (TG/2.2) [1,2].

Non-HDLC can be obtained in the nonfasting state and does not require TG to be less than 4.5 mmol/L, which is the limitation for calculation of cLDLC [44]. However, dHDLC measurement errors in hypertriglyceridemic samples still affect the calculation of non-HDLC and most assays limit the measurement of dHDLc to TG < 10 mmol/L. Despite this limitation, non-HDLC yields more accurate cardiovascular risk classification than either Friedewald cLDLC or dLDLC, and also more consistent risk scores using different manufacturers’ assays for dHDLc in the calculation [58]. Non-HDLC shows better correlation and concordance with cLDLC when using the Martin-Hopkins formula compared to the Friedewald equation in patients with atherogenic dyslipidemia [59]. When compared to Martin-Hopkins cLDLC, non-HDLC translates to only modest improvement for risk classification that could change clinical management (in ~2% of individuals in a general population), although discordance of Martin-Hopkins cLDLC and, as a consequence, risk underestimation is still common (80–90%) in patients with TG ≥ 4.5 mmol/L [60].

7.2. Apolipoprotein B

In contrast to the heterogeneous LDLC fraction, apoB is a clearly defined measure. It is the structural protein for all non-HDL lipoproteins and exists as 2 isomers: apoB100, the major isomer in VLDL, IDL, LDL, and Lp(a), and apoB48 in chylomicrons and chylomicron remnants [12]. ApoB100 contains the ligand that binds to the LDL receptor. Since each atherogenic particle contains one molecule of apoB, concentrations of apoB are therefore considered to be a direct measure of the total number of lipoproteins causing cardiovascular disease, that is, LDL, remnants, and Lp(a) [12].

ApoB quantification by automated immunoassays such as immunonephelometry and immunoturbidimetry can be easily implemented in the clinical laboratories. These immunoassays obviate the need for lipoprotein subtraction techniques such as nuclear magnetic resonance (NMR) spectroscopy or ion mobility to quantify LDLP and have been shown to be at least equivalent to LDLP in predicting cardiovascular risk [61,62]. However, apoB cannot substitute for NMR- or ion mobility-based particle size measurements and does not differentiate between LDL and VLDL particle numbers [61,62]. A major impediment to LDLP testing is its limited availability in the clinical laboratories, higher cost, and lack of standardization [63], although it does provide additional information on other lipoproteins VLDL and HDL, beyond LDLP.

ApoB can be measured in the nonfasting state because even at peak postprandial concentrations, the number of chylomicron-apoB48 particles in healthy individuals is usually < 1% and the number of VLDL-apoB100 particles is < 10% of the number of LDL-apoB100 particles [12]. Thus, even when cross-reactivity of immunoassays to apoB48 occurs in nonfasting measurements, apoB quantification is essentially an estimate of LDL particle number if TG and Lp(a) concentrations are low [1]. Far higher than the maximum allowed TG concentration of 4.5 mmol/L for cLDLC, most nephelometric and turbidimetric apoB measurements are limited to TG < 10 mmol/L due to interference of light scattering or absorption caused by chylomicrons and large VLDLs; a TG concentration above this limit in nonfasting blood samples is only seen in ~0.1% of individuals in the general population [17]. Nevertheless, it is cautious to consider fasting apoB measurement when TG concentration in the nonfasting sample is ≥ 4.5 mmol/L [2].

The International Federation of Clinical Chemistry (IFCC) and World Health Organization (WHO) developed the SP3 reference material, value-assigned using immunonephelometry as interim reference method for apoB [64]. Common calibration with the IFCC/WHO SP3 reference material has reduced between-laboratory variability of apoB measurements from > 19% to < 10%, although concerns about the variability among immunoassays and their comparability with apoB100 derived from NMR and other methods still exist [65–67]. Liquid chromatography tandem-mass spectrometry (LC-MSMS)-based quantification of apolipoproteins has the potential to further improve apoB100 standardization and between-method comparability [67]. The IFCC has therefore initiated development of LC-MSMS as candidate definitive reference method for apoB [67]. Another advantage of LC-MSMS is that it enables the simultaneous (multiplexed) measurement of multiple apolipoproteins in addition to apoB100 in a single run of the assay, thus making it possible to achieve a complete apolipoprotein profile in the patient, including HDL- and VLDL-associated apolipoproteins for comprehensive characterization of dyslipidemias [68]. Although nowadays throughput of LC-MSMS is low compared to immunoassays, automated LC-MSMS systems are developed and will become available for implementation in high-throughput clinical laboratories.

Given the improvements of standardization initiated by the IFCC [69], measurements of apolipoproteins have the potential to meet

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Primary and secondary goals of preventive therapy according to cardiovascular mortality risk categories assessed with the SCORE system [4].</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk (SCORE)</td>
<td>LDLc (mmol/L mg/dL)</td>
</tr>
<tr>
<td>Very high</td>
<td>&lt; 1.4 (55)</td>
</tr>
<tr>
<td>High</td>
<td>&lt; 1.8 (70)</td>
</tr>
<tr>
<td>Moderate</td>
<td>&lt; 2.6 (100)</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; 3.0 (115)</td>
</tr>
</tbody>
</table>

Very high risk = documented ASCVD, diabetes with target organ damage (proteinuria, retinopathy or neuropathy), or early onset type 1 diabetes of > 20 years duration, severe chronic kidney disease (GFR < 30 mL/min/1.73 m²), SCORE ≥ 10%; High risk = TC > 8 mmol/L (310 mg/dL), LDLC > 5 mmol/L (190 mg/dL), FH, hypertension ≥ 180/110 mmHg, diabetes of ≥ 10 years duration without target organ damage, moderate chronic kidney disease (GFR 30–59 mL/min/1.73 m²), SCORE ≥ 5% and < 10%; Moderate risk = young patients with diabetes (type 1 < 35 years, type 2 < 50 years) of < 10 years duration, SCORE ≥ 1% and < 5%; Low risk = SCORE < 1%.

To convert mmol/L to mg/dL, multiply with 38.6 for LDL and non-HDL cholesterol.

a Ten-year risk of fatal ASCVD as estimated using SCORE (Systematic Coronary Risk Evaluation) [4].
b Secondary target in patients with mild-to-moderate hypertriglyceridemia, 2–10 mmol/L (175–880 mg/dL) including those with obesity or metabolic syndrome, diabetes, or chronic kidney disease.
c Discordant high non-HDLC at optimal LDLC goal reflects elevated RemnantC > 0.8 mmol/L (30 mg/dL).
d Discordant high apoB at optimal LDLC goal reflects elevated numbers of small, cholesterol-depleted LDL particles.
analytical performance criteria including accuracy, harmonisation across laboratories, unambiguous definition of the measurand, and unequivocal test results in both normo- and dyslipidemic sera – important prerequisites for medical use of a test which can not be met with LDLc and non-HDLc measurements or calculations.

**Recommendation.**

- ApoB measurement is superior to LDLc and non-HDLc measurements and calculations for the assessment of exposure to atherogenic lipoprotein particle numbers in the circulation.
- ApoB is recommended for risk assessment and may be preferred over non-HDLc, if available, in persons with mild-to-moderate hypertriglyceridemia (2–10 mmol/L), diabetes, obesity or metabolic syndrome, or very low LDLc < 1.8 mmol/L [4].
- Like non-HDLc, apoB can always be measured in the nonfasting state and is not affected by biological TG variability.

**8. Can apoB measurement replace the standard lipid profile for monitoring of lipid-lowering therapies?**

Although the traditional lipid profile of TC, TG, HDLc, and LDLc remains essential for dyslipidemia diagnosis and ASCVD risk categorization, the position of LDLc as treatment target is challenged by the analytical performance of apoB. However, the apoB test has not yet been completely validated for this clinical purpose according to key criteria defined by the EFLM Test Evaluation Working Group [70] – clinical performance, clinical effectiveness, and cost-effectiveness – beyond analytical performance to become a medically useful test (Table 7).


Data and meta-analyses of prospective population-based cohort studies [71–74] and statin trials [75,76] suggest that the clinical performance of apoB and non-HDLc, although superior to LDLc in some studies, is on average comparable to dLDLc, Friedewald cLDLc or Martin-Hopkins cLDLC to predict risk of fatal or nonfatal ASCVD on the population level. Risk associations are similar in nonfasting study populations than in those who did fast [72,74].

For a majority of patients in whom apoB tests correlate with LDLc, measurement of traditional lipids should suffice to estimate risk. However, in ~20% of individuals in whom apoB is discordantly high with respect to population percentiles of LDLc, cardiovascular risk tracks with apoB, suggesting that replacing LDLc by apoB would identify more individuals with increased risk of ASCVD [74] – this implies an overall better clinical performance compared to LDLc in particular among this smaller subset of individuals with discordant apoB.

**8.2. Clinical effectiveness – risk reduction**

The substantial residual risk that persists in LDLc-targeted therapies even at LDLc < 1.8 mmol/L has fueled the debate about considering using apoB rather than LDLc as treatment target. Meta-analyses of lipid-lowering trials showed that statins and other therapies which clear apoB-containing lipoproteins by upregulating LDL receptor expression, such as PCSK9 inhibitors, reduce cardiovascular risk proportional to the decrease in apoB concentration observed in these trials [77,78]. Furthermore, Mendelian randomization studies demonstrated that the reduction in cardiovascular risk associated with genetic variation in clearance and processing of apoB-containing lipoproteins, including LDL particles as well as TG-rich VLDL particles and their remnants, was correlated with the change of concentration of these particles as measured by apoB rather than the cholesterol mass carried by those particles as measured by LDLc [79,80]. These findings suggest a potential role of apoB as therapeutic target.

**8.3. Cost-effectiveness – health economic benefit**

Implementation of apoB assays in follow-up of lipid-lowering therapies would impose healthcare systems and patients with yearly extra cost, although one might consider replacing the standard lipid profile (needed for calculation of LDLc and non-HDLc) by single follow-up measurement of apoB in order to attenuate the rise of expenses. The suggested use of apoB would be cost-effective if these tests guide therapy to reduce the healthcare costs of ASCVD to a greater extent than standard therapy guided by LDLc, yet the evidence base of this approach is still incomplete (Table 7). To evaluate cost-effectiveness of apoB-guided treatment, randomized trials should be designed in

---

Table 7

Contemporary evidence for the medical use of LDLc, non-HDLc, apoB, and LDLP based on essential test characteristics [1]. Test characteristics defined by the EFLM Test Evaluation Working Group [70].

<table>
<thead>
<tr>
<th>Test characteristics</th>
<th>LDLC</th>
<th>non-HDLc</th>
<th>ApoB</th>
<th>LDLP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analytical performance</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precise assay</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Accurate assay</td>
<td>No</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Nonfasting measurement possible</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Widely accessible assay</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Reasonable operational costs</td>
<td>Yes</td>
<td></td>
<td>No extra measurement</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Clinical performance</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robust associations with incident ASCVD?</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Novel information beyond existing markers?</td>
<td>(Reference)</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Validated decision thresholds?</td>
<td>No</td>
<td></td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Clinical effectiveness</strong>&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superiority to existing tests?</td>
<td>(Reference)</td>
<td></td>
<td>Probably</td>
<td>Probably</td>
</tr>
<tr>
<td>Modifiable risk association (treatment target)?</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Test-guided treatment reduces ASCVD risk?</td>
<td>Yes</td>
<td></td>
<td>Probably</td>
<td>Unknown</td>
</tr>
<tr>
<td><strong>Cost effectiveness</strong>&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test-guided treatment saves healthcare costs?</td>
<td>Yes</td>
<td></td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

<sup>a</sup> Analytical validity: ability of the test to conform to predefined quality specifications to measure the marker of interest.

<sup>b</sup> Diagnostic or prognostic accuracy: ability of the test to consistently discriminate patients with increased risk from those with lower risk for developing ASCVD.

<sup>c</sup> Clinical utility: ability of the test to improve health outcomes of the patient under standard clinical care.

<sup>d</sup> Health-economic advantage of introducing the test in medical practice (value for money).
which patients are randomized to receive the apoB test vs. the standard LDL-C test and the health economic outcome(s) of identifying and treating more patients at high risk (i.e., not identified or treated when using the standard test) is assessed [1].

**Recommendation.**

- At this point of time, there is insufficient evidence of benefit from outcome studies to support the option to replace the standard lipid profile (with calculation of cLDLC and non-HDLC) by single follow-up measurement of apoB to guide lipid-lowering therapies.
- The clinical effectiveness of LDL-C-guided management of cardiovascular risk is most strongly evidence-based [7,8]. All guidelines concur that LDL-C remains the primary target of lipid-lowering strategies to prevent ASCVD [4–6]. Lowering LDL-C to concentrations below a target of 1.8 mmol/L in patients at high cardiovascular risk or 1.4 mmol/L in patients at very high risk (or by ≥ 50% if these targets cannot be attained) is of critical importance [4].

9. Should non-HDL-C or apoB be used as additional tests to LDL-C in lipid-lowering strategies?

9.1. Non-HDL cholesterol

Data from concordance/discordance analyses suggest that calculation of non-HDL-C is at least equally good at predicting ASCVD compared with measurement or calculation of LDL-C in the overall population and statin-treated patients; it may also be superior to LDL-C if discordantly high, especially at normal or low LDL-C concentrations and in individuals with hypertriglyceridaemia because it includes Remnant C [81–83]. LDL-C does not provide incremental risk prediction of ASCVD relative to non-HDL-C [81–83]. The only concern is the threshold concentration selected in some studies: it may be the more sensitive threshold for non-HDL-C as compared to LDL-C rather than the biomarker which makes the difference. Guideline-based non-HDL-C thresholds have been arbitrarily defined by consensus of expert groups, based on the assumption that a normal VLDL-C concentration exists when TG are < 1.7 mmol/L, which is < 0.8 mmol/L as estimated by the Friedewald formula [1,2]. Lowering non-HDL-C thresholds leads to upward reclassification of patients (if the goal is to reduce under-treatment), higher thresholds lead to downward reclassification (if the goal is to reduce overtreatment). Threshold values need to be validated in clinical performance studies, to evaluate which values most accurately classify patients within risk categories [70].

For the present purposes, the combination of non-HDL-C with Martin-Hopkins cLDLC may be considered as an appropriate strategy to guide therapy and they can be calculated from the standard lipid profile [1]. This may compensate for the under- or overestimation of LDL-C in terms of clinical decision making, given the uncertainty of cLDLC measurements or the Friedewald calculation in dyslipidemic samples when LDL-C lowering approaches 1.4 mmol/L, and non-HDL-C can be used at high TG ≥ 4.5 mmol/L. However, the compromised accuracy of dHDL-C assays in samples with hypertriglyceridaemia reduces the benefit in reporting non-HDL-C in some individuals in whom an apoB or LDL-C measurement may be clinically useful [1].

9.2. Apolipoprotein B

Data from concordance/discordance analyses in large case-control and prospective cohort studies reveal that the addition of apoB to LDL-C and even to non-HDL-C has the potential to improve risk prediction by identifying more high-risk individuals [74,84–86]. This is consistent with the notion that risk of ASCVD is more directly related to the number of apoB-containing particles (reflected by apoB measurement) than to the cholesterol content of lipoproteins [10]. The implication of discordant LDL-C vs. apoB (one normal, the other high) is most evident in patients with predominant small, cholesterol-depleted LDL particles who present with “optimal” concentrations of TC and LDL-C – a profile that is especially prevalent among individuals with the metabolic syndrome or diabetes and in those taking medications, such as statins and anti-PCSK9, that reduce LDL-C to a greater extent than apoB [87–89]. This necessarily results in on-treatment LDL-C and VLDL-C particle numbers that are higher than would be anticipated from the concurrent LDL-C follow-up measurement and may explain part of residual risk among statin-treated patients [62,90].

In patients with a moderate estimated risk score, in particular those with additional metabolic risk factors, apoB (or LDL-P) measurement as a “risk-enhancing factor” could be useful [6]. Presence of risk-enhancing factors including apoB can tip the balance toward earlier initiation of drug treatment in shared decision making between clinician and patient, especially in primary prevention if goals cannot be achieved with lifestyle advice [6].

9.3. Secondary treatment target: non-HDL-C or apoB?

Guidelines propose using non-HDL-C or apoB as a secondary treatment target in the management of patients with mild-to-moderate hypertriglyceridaemia (2–10 mmol/L), including patients with diabetes [4,5]. If the primary target LDL-C is at goal, but non-HDL-C or apoB are still high, attainment of all three targets will require intensified lipid-lowering therapy, lifestyle (re)inforcement, and/or additional TG-lowering drugs (e.g., fibrate or omega-3 fatty acids) [4]. Addition of PCSK9 inhibition to statin therapy allows more patients to achieve non-HDL-C and apoB goals and lower risk of ASCVD, with no attenuation of benefit at lower concentrations [88].

Which to choose as secondary target: non-HDL-C or apoB? Although apoB demonstrates competitive clinical performance compared with non-HDL-C, there is no evidence yet of significant population health-economic benefit of intensifying pharmacological intervention aiming to further reduce apoB at very low concentrations of LDL-C [1]. For now and until this issue is clarified, non-HDL-C is an acceptable choice and it can be used without the additional expense of extra measurement.

**Recommendation.**

- Use of non-HDL-C or apoB should be considered as an index of the efficacy of treatment targeted at LDL-C. For the present purpose, every lipid profile report should automatically add non-HDL-C. To improve patient comfort and compliance, there are practical advantages of this approach for follow-up without the need to fast [2].
- At TG concentration ≥4.5 mmol/L, a condition wherein use of Friedewald cLDLC or Martin-Hopkins cLDLC is not recommended and also dLDLC is likely to be inaccurate, use of non-HDL-C calculation may be considered instead of dLDLC measurement to evaluate therapeutic response.

10. How to report the atherogenic lipid profiles?

10.1. Threshold values

We recommend that laboratory reports should flag abnormal concentrations based on threshold values defined by guidelines, i.e., decision threshold to trigger therapy or to identify increased risk of ASCVD (Table 8). For nonfasting samples, laboratories should flag abnormal TG concentrations as ≥ 2 mmol/L according to the Women’s Health Study, which found that this threshold was optimal for ASCVD prediction [91]. The threshold for fasting TG at 1.7 mmol/L is 0.3 mmol/L lower than for nonfasting TG, corresponding to the mean maximal increase in TG following habitual food intake [2]. Nonfasting state-adjusted thresholds for RemnantC and, consequently, also non-HDL-C may be considered as an option (Table 8). In case the patient’s postprandial time in the preceding 12 h is unknown on sample reception in the laboratory, it may
remain prudent to apply the lower fasting thresholds to draw attention to a potential cardiovascular risk.

For LDLC, the decision threshold for initiation of therapeutic intervention varies with the individual's risk score (Table 6) [4]. This personalized reporting of optimal thresholds is difficult to implement in laboratory reports because usually the clinical conditions and risk factors of the individual patients are not known to the laboratory personnel. We therefore propose a simplified flagging based on the threshold for low risk only (3 mmol/L), which may be complemented by more detailed information on risk-stratified thresholds in footnotes on the laboratory report or by references to web-based information [2].

Given the uncertainty of measurements and calculations of LDLC across different methods and laboratories, in hypertriglyceridemic patients the decision thresholds may not always be assumed to be universally applicable [1]. Guideline-recommended LDLC thresholds are based on observations with Friedewald clDLC using the older HDLC precipitation methods which differ from dHDLC assays used nowadays. This situation is challenging for new generation assays to meet regulations for in vitro diagnostic medical devices, requiring evidence of clinical performance of the assays [70].

### Table 8

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Thresholds</th>
<th>Interpretative commenting</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG</td>
<td>Fasting ≥ 1.7 mmol/L (150 mg/dL)</td>
<td>&gt; 10 mmol/L (880 mg/dL): severe hypertriglyceridemia with high risk of acute pancreatitis</td>
</tr>
<tr>
<td></td>
<td>Nonfasting ≥ 2 mmol/L (175 mg/dL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥ 5 mmol/L (190 mg/dL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥ 3 mmol/L (115 mg/dL)</td>
<td>&gt; 13 mmol/L (500 mg/dL); consider homozygous FH</td>
</tr>
<tr>
<td>Remnant C</td>
<td>Fasting ≥ 0.8 mmol/L (30 mg/dL)</td>
<td>&gt; 5 mmol/L (190 mg/dL); consider heterozygous FH</td>
</tr>
<tr>
<td>Non-HDLC</td>
<td>Fasting ≥ 3.8 mmol/L (145 mg/dL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonfasting ≥ 3.9 mmol/L (150 mg/dL)</td>
<td></td>
</tr>
<tr>
<td>ApoB</td>
<td>≥ 1 g/L (100 mg/dL)</td>
<td>&lt; 0.1 g/L (10 mg/dL): genetic abetalipoproteinemia</td>
</tr>
<tr>
<td>HDLC</td>
<td>Men ≤ 1 mmol/L (40 mg/dL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Women ≤ 1.2 mmol/L (45 mg/dL)</td>
<td>&lt; 0.1 g/L (10 mg/dL): genetic hypothyroidism</td>
</tr>
<tr>
<td>ApoA-I</td>
<td>Men ≤ 1.2 g/L (120 mg/dL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Women ≤ 1.4 g/L (140 mg/dL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥ 50 mg/dL (&gt; 105 mmol/L)</td>
<td>&gt; 120 mg/dL: very high risk for myocardial infarction and aortic valve stenosis</td>
</tr>
<tr>
<td>Lp(a)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values in mmol/L were converted to mg/dL by multiplication with 38.6 for cholesterol and 88.5 for TG, followed by rounding to the nearest 5 mg/dL.

* TG thresholds based on assays with correction for endogenous glycerol. The free glycerol concentration in a sample, usually 1 mg/dL, equivalent to ~10 mg/dL (0.11 mmol/L) of TG, can be ignored. Increased baseline glycerol concentrations can be found in patients with diabetes and chronic kidney disease and during intravenous lipid infusion, and TG may be wrongly flagged in these patients unless glycerol-corrected TG assay is used.

** Threshold value for Lp(a) should represent ≥80th percentile of the population-specific Lp(a) assay.

### 10.2. Reference limits

Usually, in laboratory reports, results of most tests are flagged if they are below or above the age- and sex-specific reference interval (2.5th to 97.5th percentiles). Because of the widespread unhealthy lifestyle, in most populations the upper reference limits of TC, LDL-C, and TG are very high and far above the thresholds of increased ASCVD risk (Tables 2-3, Fig. 2). Therefore, flagging of lipid profiles in adults should not be based on reference limits [2]. In a pediatric setting, reporting age- and gender-specific reference intervals is relevant for early identification of children with hyperlipidemia associated with premature atherosclerosis, especially FH [32].

Reference nonfasting concentrations in adults from the Copenhagen General Population Study are reported in Tables 2-3. Reference intervals in children and adolescents are available from recent population-based cohort studies and databases [92–94]. Countries are encouraged to establish reference intervals in their local populations, to account for differences in lifestyle and risk factors in different European regions. Ideally, these reference intervals should be regularly updated because significant changes in population lipid concentrations occur mainly related to the substantial increase in unhealthy lifestyle and obesity and changes of analytical methods over time [95–97]. In the adoption of published reference concentrations with known biological or analytical sources of variation, the clinical laboratory should verify the reference interval with its own analytical method on 20 samples drawn from its local population under similar pre-analytical conditions [96,97]. If ≤ 2 of 20 values (≤10%) fall outside the reference interval then the interval can be adopted [96,97]. For decision thresholds it is unnecessary to validate them in the laboratory [97].

### 10.3. Alert values

Using decision thresholds for flagging will lead to many lipid profiles reported with flags, as with more than 50% of LDLC results (Fig. 2). There is a risk that flagging too many results will make the physician ignore very high concentrations and may distract from the severe dyslipidemias, especially when used for screening in primary care. We have considered this by defining alarming values for extreme dyslipidemias, where we recommend special notification and reaction from the laboratory [2].

Extremely abnormal test results should be flagged with special alert notifications to quickly initiate further diagnostic and possibly therapeutic actions by the clinician (Table 8). For example, patients with severe hypertriglyceridemia ≥10 mmol/L and chylomicronemia syndrome have high risk of acute pancreatitis but usually do not develop premature atherosclerosis, probably because chylomicrons and large VLDLs do not traverse the vascular endothelial barrier [33]. Lp(a) above the 97.5th percentile (>120 mg/dL depending on the assay) should be noted because of very high risk for myocardial infarction and aortic valve stenosis [2]. Any LDLC > 5 mmol/L in adults or > 4 mmol/L in children should trigger investigations to rule-out FH and, if diagnosis of FH is confirmed in the index case, cascade family screening [31,32]. In patients with mixed hyperlipidemias, routine genetic testing is not warranted [33]. Reflective testing can proactively assist clinicians to rule-out common secondary causes of hyperlipidemia using
additional tests, e.g., thyrotropin, haemoglobin A1c, liver enzymes and creatinine/eGFR, if not already known to the clinician at first-time screening [98].

Recommendation.

- Flagging of lipid profiles on laboratory reports should always be based on decision thresholds. In children, reporting of reference intervals is relevant.
- Extremely high concentrations should automatically trigger alerts to initiate immediate diagnostic investigations.

11. Conclusion and future research priorities

The consensus-based recommendations of EAS and EFLM provide guidance for the use of contemporary lipid, lipoprotein, and apolipoprotein tests to assist clinicians in their strategies to prevent ASCVD [1,2]. These recommendations take into account the strengths and weaknesses of the tests in terms of key criteria to become a medically useful test, as defined by the EFLM Test Evaluation Working Group [70].

Calculation of non-HDLC and RemnantC from the standard lipid profile, ‘expanded’ testing of apoB and Lp(a), and ‘advanced’ testing of LDLP have the potential to address clinical needs unmet with LDLC testing and they can always be used in nonfasting samples. The research priority is to investigate whether the diagnostic information provided by ‘expanded’ or ‘advanced’ lipid profiles can sufficiently change clinical management to reduce the risk (and cost) of ASCVD to a greater extent than the standard LDLC-centered approach.

Diabetes and abdominal obesity, disorders that underlie the clinical expression of complex dyslipidemias without elevated LDLC, are attaining epidemic proportions [11]. Hence, emerging and advanced lipoprotein testing will likely become more and more useful in the future. This underscores the need to standardize and validate advanced lipoprotein tests, such as NMR- or ion mobility-based LDL- and VLDL-particle numbers and size [62,63], and multiplexed LC-MSMS apolipoprotein profiles [68], which have the potential to become widely available medical tests [99]. These novel technologies provide complementary diagnostic information regarding the complex molecular basis of dyslipidemias and, as such, can be used to explore and evaluate precision medicine approaches for identifying better and individualized treatment options for patients at high risk of ASCVD [99].

Author contribution

EAS-EFLM Joint Consensus Panel members were nominated by EAS, EFLM and the co-chairs M.L. and B.G.N. to represent expertise across clinical and laboratory management and lipid research from across the World. The Panel met twice, organized and chaired by M.L. and B.G.N. The first meeting critically reviewed the literature while the second meeting reviewed additional literature and scrutinized the first drafts of the joint consensus statements.

This summary embodies the consensus-based recommendations produced by the Panel [1,2] and was critically reviewed by independent experts of the EFLM Task Group on Cardiac Markers, chaired by P.L., who were not present at the first Panel meetings. The recommendations should be considered as consensus-based expert opinion, despite the high-quality evidence base available from systematic reviews and meta-analyses of randomized controlled trials, Mendelian randomization studies, and prospective population-based cohort studies for most recommendations. All Panel members agreed to conception and design, contributed to interpretation of available and additional novel data, and all suggested revisions for this document.

A first version of the document underwent public consultation by the EFLM National Societies. Comments were received from 11 Societies and have been taken into account during the revision of this document. The revised version has been sent for final voting to all 40 National Societies. The document was positively voted by 29 Societies (1 negative vote was received and 10 Societies did not vote).

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