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Pediatric lipid reference values in the general population: The Dutch lifelines cohort study



J. W. Balder, MD, PhD, P. J. Lansberg, MD, PhD, M. H. Hof, MSc, A. Wiegman, MD, PhD, B. A. Hutten, PhD, J. A. Kuivenhoven, PhD*

Department of Pediatrics, Section Molecular Genetics, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands (Drs Balder, Lansberg, and Kuivenhoven); Department of Vascular Medicine, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands (Dr Balder); Department of Clinical Epidemiology, Biostatistics and Bioinformatics, Academic Medical Center, University of Amsterdam, Amsterdam, The Netherlands (Drs Hof and Hutten); and Department of Pediatrics, Emma Children's Hospital, Academic Medical Center, University of Amsterdam, Amsterdam, The Netherlands (Dr Wiegman)

KEYWORDS:

Familial hypercholesterolemia; Dyslipidemia; Normal values; Cholesterol levels; Population study; Children

BACKGROUND: Atherosclerosis starts in childhood and its progression is influenced by lifelong low-density lipoprotein cholesterol (LDL-c) exposure, the so-called cholesterol burden. Early identification of children and adolescents with severely elevated LDL-c is thus of major clinical significance. This is especially true for children with familial hypercholesterolemia (FH), a frequent but undertreated genetic disorder. To identify children with possible FH, insight in the distribution of lipid levels in children is a prerequisite.

OBJECTIVE: To provide health care professionals with contemporary age- and gender-based pediatric reference values for lipid and lipoprotein levels to help the identification of children with dyslipidemia, especially FH.

METHODS: Lifelines is a large prospective population-based Dutch cohort study. Children from 8 till 18 years of age were included and fasting lipid levels were measured. Smoothed reference curves and percentiles (5th, 10th, 25th, 50th, 75th, 90th, and 95th) were generated using the Generalized Additive Models for Location, Scale and Shape package in the statistical software R.

RESULTS: A total of 8071 children (3823 boys and 4248 girls) were included. In the total cohort we noted marked dynamic changes in lipid and lipoprotein levels over age, which were in part gender specific. Our data highlight a high and unexpected prevalence of severely elevated LDL-c (>190 mg/dL) in both boys and girls.

CONCLUSION: Our cross-sectional data provide contemporary reference ranges for plasma lipids that can assist physicians in identifying children at increased risk of premature atherosclerosis, especially FH.

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* Corresponding author. Department of Pediatrics, Section Molecular Genetics, University of Groningen, University Medical Center Groningen, Antonius Deusinglaan 1, 9713 AV, Groningen, The Netherlands.

E-mail address: j.a.kuivenhoven@umcg.nl

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Introduction

Cardiovascular disease (CVD) represents a leading cause of death globally.¹ Most often men and women above 55 and 65 years of age, respectively, are affected, but fatty streaks start developing at a very young age and the

progression of atherosclerosis is positively associated with plasma low-density lipoprotein cholesterol (LDL-c) exposure.²⁻⁴ This progression is accelerated in individuals with familial hypercholesterolemia (FH), a genetic disorder characterized by elevated LDL-c levels and premature CVD. Mutations in *LDLR*, *APOB*, and *PCSK9* have been shown to cause FH. The prevalence of FH is estimated to be 1 per 200 to 250 individuals but this lipid disorder is severely underdiagnosed and undertreated.^{2,3} In children with genetically confirmed FH, undertreatment is common as well.^{5,6} Carriers of FH mutations suffer from increased cardiovascular risk, related to a lifelong exposure to increased LDL-c levels.⁷ In adults, and to a lesser extent in children, identification of FH affected individuals is difficult because of the overlap of LDL-c levels in both FH and non-FH individuals.^{8,9} In this context, genetic testing can help in the clinical diagnosis of FH and in the screening of affected family members, known as cascade screening.^{10,11}

Childhood is the best period to discriminate between mutation-positive and mutation-negative hypercholesterolemia on the basis of plasma LDL-c levels only.⁹ Children with LDL-c levels twice >190 mg/dL should be considered as having FH, whereas 2 consecutive LDL-c levels >160 mg/dL in combination with a family history of hypercholesterolemia or premature CVD are highly suggestive of FH. Finally, children of affected parent(s) with an LDL-c >130 mg/dL are likely to have inherited the mutation.²

Initiation of statin treatment early in life (around 8 years) is an accepted strategy in clinical practice,^{2,12,13} which makes early identification of children with FH clinically relevant.¹⁴ To date's reference ranges are, however, based on old or small-case studies.¹⁵⁻²¹

To provide such reference ranges, we used data of Lifelines, a prospective population-based cohort study, which was initiated in 2006.^{22,23} Using the same cohort, we recently reported that lipid levels in adults are strongly age- and gender-dependent, whereas the data of participants below the age of 18 years were not yet released.²⁴ For the present study, we have generated age- and gender-based reference values for lipid levels in children, aged 8 till 18 years. These data can help the identification of children at increased risk of atherosclerosis such as children with FH and assist cascade screening in families.²

Methods

Study population

The study protocol was approved by the Medical Ethical Committee of the University Medical Center Groningen in the Netherlands, and all participants provided written informed consent. The rationale and design of Lifelines have been described previously.^{22,23} In short, Lifelines is an ongoing prospective population-based cohort study.

Between 2006 and 2013 inhabitants from the 3 northern provinces of the Netherlands (Groningen, Friesland, and Drenthe) between 25 and 50 years of age were approached by their general practitioner to participate. On a positive response, relatives (first-degree family members, including children [≥ 6 months], partner, and parents-in-law) were also invited. Individuals could also participate through self-registration. Of the 167,729 almost exclusively Caucasian participants, 14,801 are children. This multiple-generation design offers the unique opportunity to study the origins of multifactorial diseases. In total, 85,000 (51%) participants are part of a 2-generation family and 20,000 (12%) of a 3-generation family.

For the present study, we provide cross-sectional population distributions of plasma lipid levels of children screened at the baseline visit. Of the total 14,801 children, 6730 were excluded because of (1) age <8 years ($n = 5137$), because blood sampling was only performed in children aged ≥ 8 years; (2) nonfasting (defined as an overnight fast) lipid measurements ($n = 490$); and (3) missing lipids measurements ($n = 1103$). In total, 8071 children (3823 boys and 4248 girls) were included. [Supplementary Table 1](#) provides the number of children included for each year of age.

Questionnaires, physical examination, and biomaterial collection

The parents of the children received questionnaires specifically suited for the child's age. The questionnaires covered topics on lifestyle, health, nutrition, and development. A physical examination was performed including anthropometry, blood pressure measurement (10 measurements during 10 minutes using Dinamap registration), and pulmonary function tests. Fasting blood samples were drawn after an overnight fast. Fresh samples were transferred to the central laboratory of University Medical Center Groningen for routine clinical chemistry.

Cholesterol measurements

Total cholesterol, LDL-c, high-density lipoprotein cholesterol (HDL-c), and triglycerides were directly measured and were standardized against appropriate controls as described.²⁴ LDL-c levels were also calculated using the Friedewald formula,²⁵ but only when triglyceride levels did not exceed 400 mg/dL.

Statistics

Baseline characteristics that follow a normal distribution were reported as mean and standard deviation. Baseline characteristics with a skewed distribution were reported as median and interquartile range.

Smoothed reference curves were generated using Generalized Additive Models for Location, Scale and Shape.²⁶ Let $Y(t)$ be an outcome variable at age t . We used the

Box-Cox- t power transformation with parameters $\mu(t)$, $\sigma(t)$, and $\nu(t)$ to transform $Y(t)$ to $Z(t)$ with the following formula²⁷:

$$Z(t) = \begin{cases} \frac{1}{\sigma(t)\nu(t)} \left(\left[\frac{Y(t)}{\mu(t)} \right]^{\nu(t)} - 1 \right) & \text{if } \nu(t) \neq 0, \\ \frac{1}{\sigma(t)} \log \left[\frac{Y(t)}{\mu(t)} \right] & \text{if } \nu(t) = 0. \end{cases}$$

The transformed variable $Z(t)$ then follows a student t -distribution with $\tau(t)$ degrees of freedom. The relations between the age t and all 4 parameters were modeled with P -splines functions.

To compare our results to previously reported age- and gender-based percentiles, we also calculated age- and gender-based specific percentiles with corresponding age groups. All analyses were performed stratified by sex and carried out using IBM SPSS Statistics, version 22.0 (Armonk, NY: IBM Corp.) or the statistical software R (version 3.2.2).

Results

Study population

As clarified in the methods section, a total of 8071 children were included in our study. Demographic and clinical characteristics of the study population are shown in [Table 1](#). Mean age was, for both boys and girls, 12 years. Furthermore, [Table 1](#) shows that boys and girls have on average similar lipid profiles, blood pressure, and glucose levels. [Supplementary Table 1](#) shows the number of included children per year of age.

Table 1 Demographics and clinical characteristics

Characteristics	Boys	Girls
	(n = 3823)	(n = 4248)
Age (y)	12 ± 2.7	12 ± 2.8
Lipid profile (mg/dL)		
Total cholesterol	155 ± 27	162 ± 27
LDL-c	89 ± 23	93 ± 23
HDL-c	58 ± 12	62 ± 12
Triglycerides	52 (40–71)	62 (47–82)
SBP (mm Hg)	107 ± 11	106 ± 11
DBP (mm Hg)	59 ± 6	60 ± 6
Glucose (mmol/L)	4.7 ± 0.5	4.6 ± 0.5
HbA1c (%)	5.4 (3.0)	5.4 (0.3)

DBP, diastolic blood pressure; HDL-c, high-density lipoprotein cholesterol; LDL-c, low-density lipoprotein cholesterol; SBP, systolic blood pressure.

Data are expressed as mean ± standard deviation but triglycerides as interquartile range.

The associations between age and fasting lipid parameters are depicted in [Figure 1](#) for boys and girls separately, using the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles. [Supplementary Table 2](#) shows age- and gender-specific lipid percentiles, including the 5th, 10th, 50th, 90th, and 95th percentiles. In the following sections, we briefly describe the main finding for different components of the lipid profile.

Age, gender, and LDL-c levels

Boys aged 8 years presented with a median LDL-c of 89 mg/dL (95th percentile: 125 mg/dL). Over the age range studied, LDL-c dropped in boys starting at approximately 12 years of age, with the lowest values around 15 years of age. Interestingly, at ages 17 and 18 years, LDL-c appears to increase marginally.

In girls, LDL-c levels appeared to be slightly higher compared with boys. As in the boys, a drop in LDL-c was noted starting at 10 years of age, with the lowest values around 14 years of age, thus a little earlier than in boys. The increase in LDL-c at later ages (15.0–17.9) was more pronounced in girls than boys. This is clearly illustrated at 17 years of age, when LDL-c is substantially higher in girls compared with boys for both median (95 mg/dL vs 82 mg/dL) and the 95th percentile (144 mg/dL vs 126 mg/dL).

In clinical practice, LDL-c levels are often calculated using the Friedewald formula (f-LDL-c).²⁵ [Supplementary Figure 1](#) shows the absolute difference between f-LDL-c and direct measurement of LDL-c. Negative values indicate lower f-LDL-c in comparison with direct measurement of LDL-c and *vice versa* for positive values. [Supplementary Figure 1](#) indicates that the population distribution of f-LDL-c is slightly lower in both boys and girls. Overall, f-LDL-c was approximately 6 mg/dL lower as compared with direct measurement of LDL-c. Clearly, with increasing triglyceride levels, the discrepancy between direct measurement and f-LDL-c increases.

Age, gender, and HDL-c levels

At 8 years of age, HDL-c levels are very similar in boys and girls; however, our cross-sectional data show markedly different HDL-c dynamics between genders with aging. HDL-c increases in boys aged 8.0 to 10.9 years followed by a strong decrease between ages 11.0 and 14.9 years, and a subsequent stabilization. In girls, by contrast, HDL-c is generally slowly decreasing with age.

Age, gender, and triglyceride levels

At 8 years of age, triglyceride levels are lower in boys (median: 45 mg/dL; 95th percentile: 96 mg/dL) than in girls (median: 52 mg/dL; 95th percentile: 105 mg/dL). In both boys and girls, triglycerides levels increase with age over

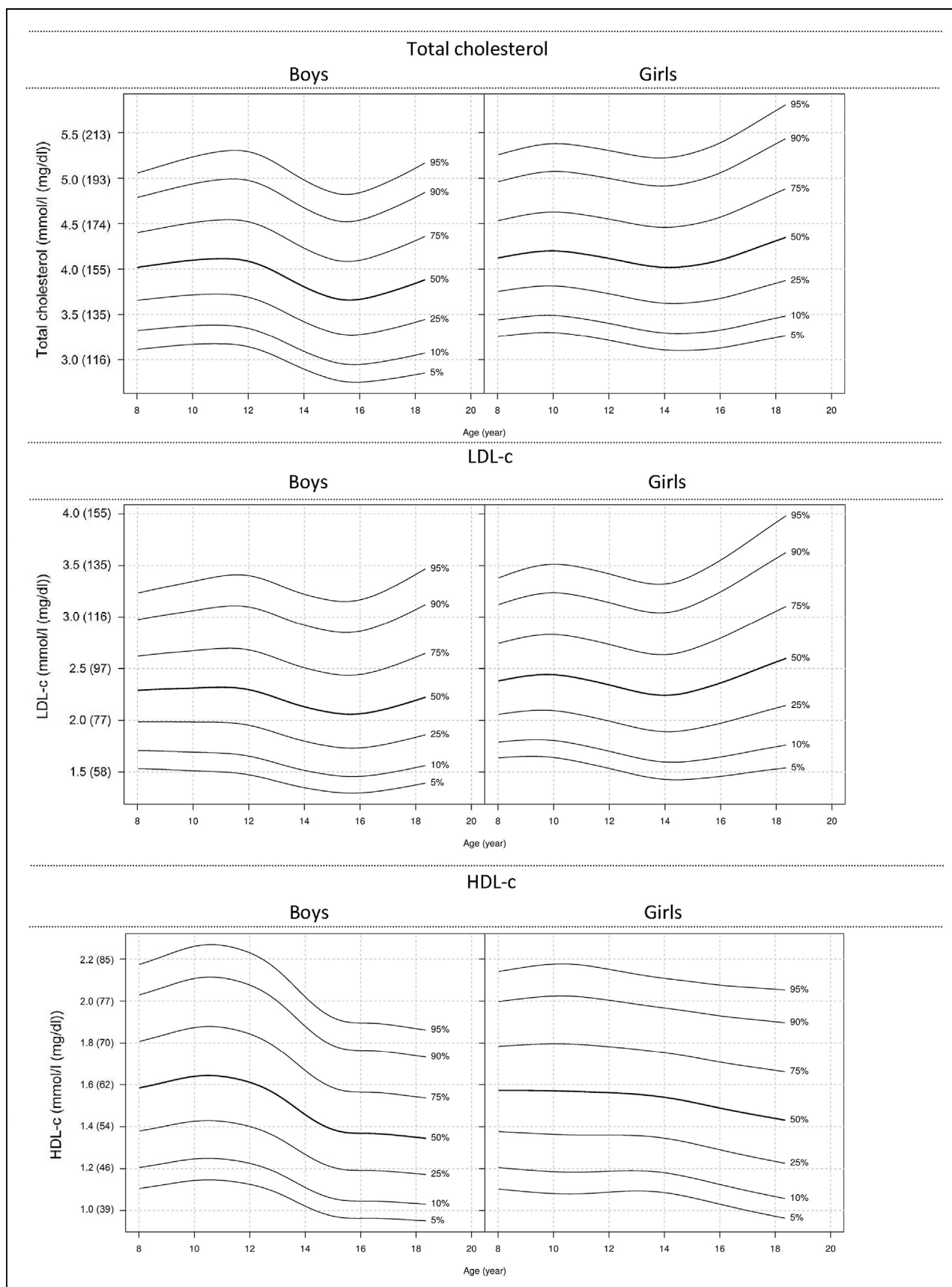


Figure 1 Relation between age, gender, and lipid parameters. Age- and gender-based smoothed percentile curves (5th, 10th, 25th, 50th, 75th, 90th, and 95th) for total cholesterol, LDL-c, HDL-c, and triglycerides for boys and girls separately. LDL-c, low-density lipoprotein cholesterol; HDL-c, high-density lipoprotein cholesterol.

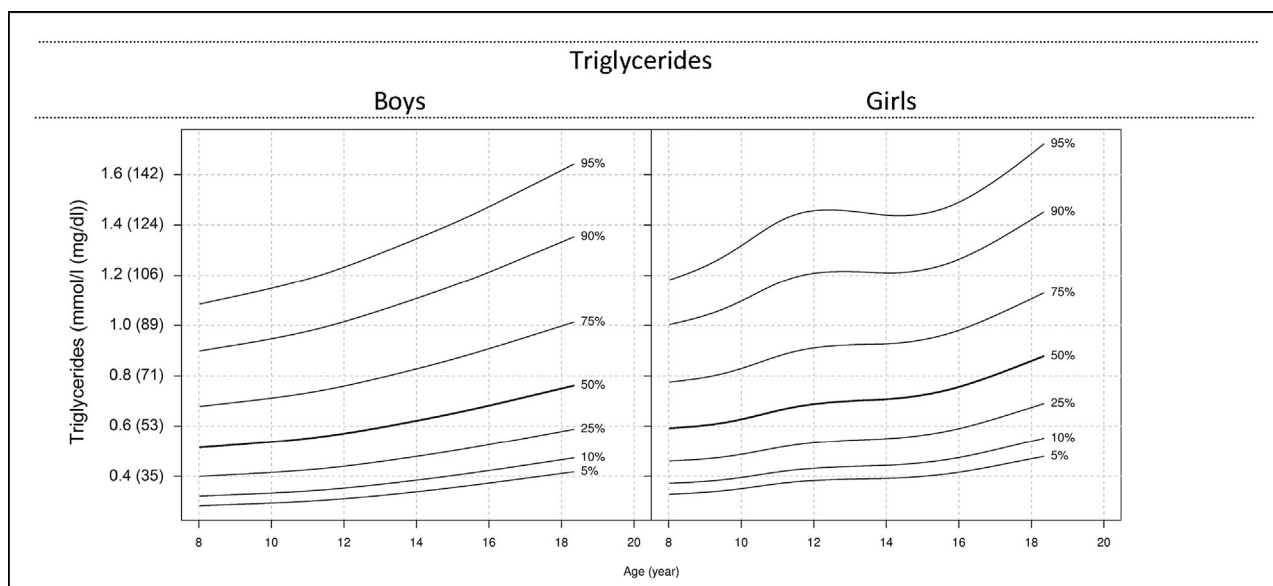


Figure 1 (continued).

all percentiles studied. At the age of 18 years, median triglycerides were 47% higher in boys and 46% higher in girls compared with the boys and girls aged 8 years.

Extremes

In our study population, a considerable number of children presented with severe hypercholesterolemia: 375 (4.6%) children presented with LDL-c levels >130 mg/dL. Eighty (1.0%) children showed LDL-c >160 mg/dL, which is a strong indicator of having FH. Eighteen children (0.22%) presented with LDL-c levels >190 mg/dL and could be considered as having FH (Table 2).

Discussion

This study provides tables with age- and gender-based percentiles for lipid and lipoprotein levels in children and adolescents, which can aid clinicians in the diagnosis of dyslipidemia, and in their decisions if additional diagnostic evaluations are indicated. This will allow to distinguish severe dyslipidemia, where pharmacological therapy might be indicated, from lipid abnormalities in

need of lifestyle advice. We believe that the presented reference ranges are a prerequisite for effective screening and identification of children and adolescents with FH. In our study population (children and adolescents of Caucasian descent), we identified a prevalence of 1:450 for FH (LDL-C > 190 mg/dL).

Importance of lipid reference values in clinical practice

Several studies have shown that young children with increased total cholesterol levels, for example above the 90th percentile, will maintain their percentile ranking over time.^{29,30} This is why timely identification and treatment of children and adolescents with severely elevated cholesterol levels, can be an important step in reducing cardiovascular events. The recommended diet of children with FH should include less consumption of total fat (<30% of calories), saturated fat (<7% of calories), and less than 200 mg of cholesterol/d. Furthermore, the consumption of heart-healthy foods such as fruit, vegetables, and whole grain should be encouraged.² Besides diet intervention, cost-effective interventions using low-cost generic

Table 2 Prevalence of dyslipidemia in lifelines, compared with Germany and the United States

Dyslipidemia	Prevalence in Lifelines n (%)	Prevalence in Germany ¹⁶	Prevalence in the United States ^{17,19}	Prevalence in Brazil ²⁸
Total cholesterol > 200 mg/dL	412 (5.1%)	7.8%	8%	–
LDL-c > 130 mg/dL	375 (4.6%)	6.1%	7%	–
LDL-c > 160 mg/dL	80 (1.0%)	–	–	–
LDL-c > 190 mg/dL	18 (0.22%)	0.23%	–	0.12%
HDL-c < 40 mg/dL	362 (4.5%)	8%	13%–15%	–
Triglycerides > 133 mg/dL	282 (3.5%)	11.7%	12%	–

HDL-c, high-density lipoprotein cholesterol; LDL-c, low-density lipoprotein cholesterol.

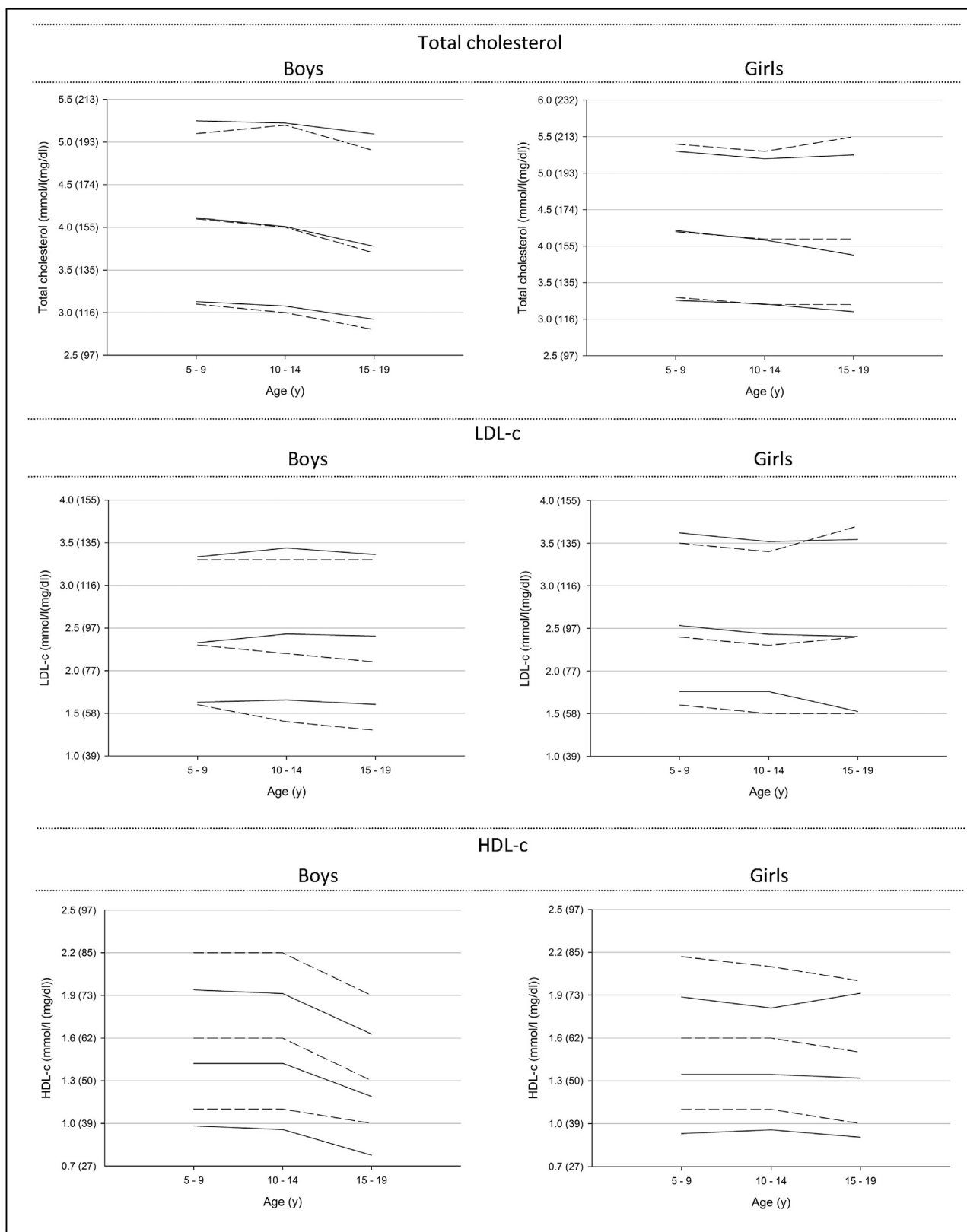


Figure 2 Comparison between lipid parameters between Lifelines and the LRC Prevalence study. Comparison of total cholesterol, LDL-c, HDL-c, and triglycerides between Lifelines (dotted line) and LRC Prevalence study (solid line). The lines correspond to the 5th, median and 95th percentile. LDL-c, low-density lipoprotein cholesterol; HDL-c, high-density lipoprotein cholesterol.

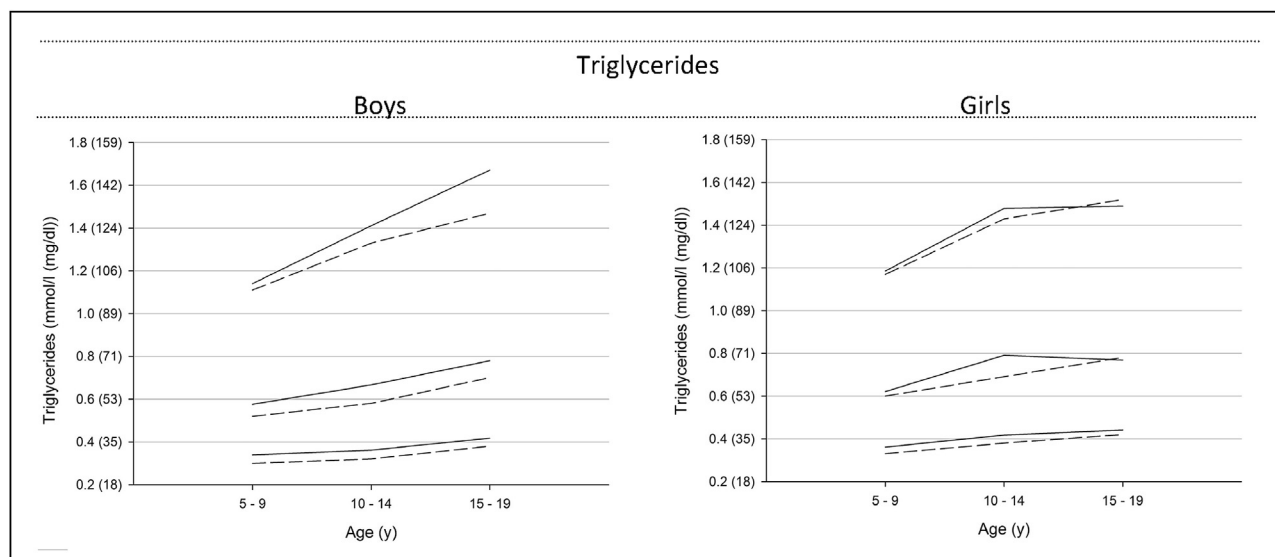


Figure 2 (continued).

statins combined with cholesterol absorption inhibitors are fundamental to FH management.³¹ Current guidelines advocate initiating statin treatment in children with FH from the age of 8 years onward.^{2,13} Although long-term data on safety and cardiovascular outcomes for statin treated children are limited, follow-up studies showed normalization of progression of carotid intima-media thickness in statin-treated FH children.^{31,32} Importantly, side-effects have been reported to be rare.^{33,34}

Screening for FH is a worldwide challenge. The most commonly used diagnostic criteria for FH (ie, Dutch Lipid Clinic Network and Simon Broome criteria) are however not applicable to children. Currently, 2 times plasma LDL-c levels >190 mg/dL is used as diagnostic criterion, whereas a threshold of 130 mg/dL is used in case of affected family members.² Universal pediatric screening of FH (phenotype-based screening) could be effectively incorporated in infant health checkups such as immunization programs.³⁵ This has been proven to be a highly effective approach, especially if reverse cascade screening to identify affected family members is integrated (genotype-based screening).^{9,36-38} Age-specific diagnostic LDL-c cutoff criteria for diagnosis of relatives with FH have been published previously.³⁹

In line with other cross-sectional studies, we show that lipid distributions change with age.^{17,18,40,41} When studying adolescents around 11–16 year of age with a pronounced fall in cholesterol levels (see Fig. 1), the use of a fixed LDL-c level for a diagnosis of FH can easily result in a misdiagnosis. In case of a clinical suspicion of FH because of, for example, familial presence of hypercholesterolemia or premature CVD, genetic testing can also provide a better tool for diagnosis. Finally, using age- and gender-specific LDL-c cutoff values can also help to identify subjects with FH as we recently showed in young premenopausal women.⁴²

Comparison with the LRC prevalence study

The LRC Prevalence study, conducted in the United States in 1970s,⁴⁰ has provided clinicians and researchers with cross-sectional lipid reference values.⁴³ Because of differences in lifestyle, cholesterol analysis methods, time of inclusion (~30 year difference), and ethnicity, dissimilarities in the distribution of lipid parameters were anticipated. After matching age groups, we compared the age- and gender-based percentiles from LRC Prevalence study with the Lifelines study (Fig. 2). LDL-c levels were lower in boys (~8 mg/dL) of the Lifelines cohort during adolescence while this discrepancy was not observed in girls. HDL-c levels were higher in both boys and girls in Lifelines compared with the LRC study, whereas triglycerides were slightly lower. The US National Health and Nutrition Examination Surveys previously showed an initial decline of total cholesterol levels in children and young adults (aged 4–19 years) between 1966 and 1970 and 1988 and 1994.¹⁵ The detrimental increase in overweight and obesity in children over the past decades,⁴⁴ which is associated with dyslipidemia,²⁸ may have reversed the initial lowering of LDL-c levels observed at that time.

Frequency of pediatric hypercholesterolemia

In our study population, 4.6% of the children presented with LDL-c levels >130 mg/dL. In the United States^{19,21} and Germany,¹⁸ higher percentages were reported, 7.0% and 6.1%, respectively (Table 2). It is possible that the lower frequency of hypercholesterolemia in our cohort is related to the use of lipid-lowering drugs, but we cannot verify this as Lifelines pediatrics questionnaires do not cover medication use. By contrast, in a pediatric Brazilian cohort (age 12–17 year),⁴⁵ the prevalence of LDL-c

>190 mg/dL was lower compared with Lifelines, but this could also be a consequence of declining LDL-c levels in adolescence. It may be noted that statements about frequencies of FH in our population are hampered by 1 time point measurements, instead of recommended repeated measurements.

Strengths and limitations

The strengths of our study are the large number of children included and that the measurement of lipid levels was performed on fresh samples in a single central laboratory. We cannot ensure that our study population is representative of the Dutch pediatric population. The adult Lifelines study cohort has, however, been described to be slightly healthier compared with the larger Dutch population,²² and it is thus likely that our pediatric cohort population is also healthier. Another limitation is that almost all Lifelines participants are of Caucasian descent, and therefore, our reference ranges may be not applicable to other ethnicities. We could not assess the relationship between pubertal stage and lipid levels as the Tanner stages of pubertal development have not been evaluated in the Lifelines cohort.

Conclusions

Our study provides contemporary age- and gender-based reference values for plasma lipid and lipoprotein levels in children and adolescents. We expect that these lipid and lipoprotein values, translated into age- and gender-specific percentiles, can serve clinicians as an effective and reliable instrument to help identifying children and adolescents with dyslipidemia, especially FH.

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Supplementary data

Supplementary data related to this article can be found online at <https://doi.org/10.1016/j.jacl.2018.05.011>.

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