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Update on LIPID MAPS classification, nomenclature, and shorthand notation for MS-derived lipid structures

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Abstract A comprehensive and standardized system to report lipid structures analyzed by MS is essential for the communication and storage of lipidomics data. Herein, an update on both the LIPID MAPS classification system and shorthand notation of lipid structures is presented for lipid categories Fatty Acyls (FA), Glycerolipids (GL), Glycerophospholipids (GP), Sphingolipids (SP), and Sterols (ST). With its major changes, i.e., annotation of ring double bond equivalents and number of oxygens, the updated shorthand notation facilitates reporting of newly delineated oxygenated lipid species as well. For standardized reporting in lipidomics, the hierarchical architecture of shorthand notation reflects the diverse structural resolution powers provided by mass spectrometric assays. Moreover, shorthand notation is expanded beyond mammalian phyla to lipids from plant and yeast phyla. Finally, annotation of atoms is included for the use of stable isotope-labeled compounds in metabolic labeling experiments or as internal standards. This update on lipid classification, nomenclature, and shorthand annotation for lipid mass spectra is considered a standard for lipid data presentation.

Supplementary key words mass spectrometry • lipidomics • fatty acyls • glycerolipids • glycerophospholipids • sphingolipids • sterols

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Lipids have become increasingly recognized as the central metabolites affecting human physiology and pathophysiology, and LIPID MAPS has recently expanded its tools, resources, data, and training as a free resource dedicated to serving the lipid research community (1). Following development of the LIPID MAPS nomenclature, classification, and structural representation system (2, 3), an initial shorthand nomenclature was proposed (4), which included a structural hierarchy as shown by others as well (5, 6). These were the first attempts to provide rules for reporting mass spectrometric data dependent on the power for structural resolution of lipids by the instrumental set-ups in use at that time.

Today, we recognize that the field has evolved in often diverging ways and that this has not enabled a unifying naming convention to be adopted throughout. For example, alternative shorthand notation has evolved for some lipid classes, a plethora of newly determined structures for lipids from various classes and phylogenetic kingdoms (higher plants and yeasts) have been described, and progress in the technological development of mass spectrometers with greater structural resolution as well as advances in automation in interpreting high-throughput data has occurred. To address this, it is the aim of this report to take into account these developments and to present an update on the LIPID MAPS classification and a pragmatic highly usable shorthand notation for those active in lipid research.

This update will focus on five of the eight LIPID MAPS categories (2), namely Fatty Acyls (FA), Glycerolipids (GL), Glycerophospholipids (GP), Sphingolipids (SP), and Sterols (ST). Annotation is modified to permit annotation of oxygenated lipids and examples will be given for lipid classes occurring outside the mammalian kingdom.

“Biological intelligence” has been considered as topical knowledge about a lipid molecule, such as its structural building blocks, enzymatic pathways for generation and metabolism, and biological functions (4). Interpretation by biological evidence in shorthand notation can be useful when mass spectra contain structural ambiguities or lack of clear structural evidence. Consequently, annotations with the help of biological evidence contain assumptions, and it must be recognized and recorded that this may lead to misinterpretations. Moreover, in the pragmatic approach presented in this work, we will make more use of common and/or trivial names for the shorthand notation. For example, the structures of sterols, prostaglandins, resolvins, etc. have been characterized by chemical and spectroscopic methods, including stereochemistry, and common names exist, as do shorthand notations in many cases. Their mass spectra are also known; however, their stereochemistry and isomerism and other structural information often cannot be deduced directly from the spectra when these lipids are measured in biological samples. Assignment of a common name or of shorthand notation to such chromatographic and MS/MS data is permissible, but it may be based on annotation that includes biological intelligence, and that needs to be clearly stated as well.

In any case, assumptions made should be striking a unique balance between *what we think we know about structure and function of a lipid molecule* and *what a specific MS-based analytical method definitively informs us about the lipid structure*.

UPDATE ON NOMENCLATURE AND CLASSIFICATION

Modification of Fatty Acyls by oxygen, either catalyzed enzymatically or by means of radical chemistry, is an important focus in biomedical research, due to the impressive biological activities of products thus obtained. Based on these two mechanisms, all compounds originating from polyunsaturated fatty acyls (PUFAs) having methylene-interrupted *cis*-double bonds (DBs) (also chemically referred to as allylic DBs) and being enzymatically or nonenzymatically oxygenated are grouped within the appropriate class in the Fatty Acyl category. Historically, the term “eicosanoid” has included “related oxygenated polyunsaturated fatty acids” with shorter or longer chain lengths, but in the LIPID MAPS classification, compounds are strictly assigned to a class based on their chain length (e.g., octadecanoids, eicosanoids, docosanoids). Recently, the common name “oxylipins”, standing for “oxygenated fatty acyls”, has come into widespread use. Similarly, in the Glycerophospholipids (GP) category, many newly described phospholipids contain oxygenated fatty acyls (or oxylipins) often termed “oxygenated phospholipids” (OxPLs). Those are produced

by oxygenation of constituent fatty acyls enzymatically and nonenzymatically, or by chemical modification of polar head groups containing an amino function (PE and PS), i.e., *N*-modified phospholipids.

In the following, we elaborate first on experimental prerequisites for correct annotation of lipid mass spectrometric data and, second, present the updates on rules for using shorthand notation. Finally, in order of categories, we present mostly in the form of easily readable tables, all updates on lipid nomenclature and classification including respective shorthand abbreviations according to the LIPID MAPS web resources and the updated shorthand notation for lipid species and lipid molecular species. To further enhance the understanding of shorthand notation, some chemical structures are presented in the tables. The updated shorthand notation schemes described herein have been incorporated into a number of key resources on the LIPID MAPS website, notably the LIPID MAPS Structure Database (LMSD) and the MS search tools (see the Hierarchical concept and application of shorthand notation section below), by generating level-specific abbreviations (e.g., sum-composition and chain-specific annotations) for lipid structures. This approach is important in terms of the development of MS search databases that are appropriate for the technique used (sum-composition databases for precursor ion data and chain-composition databases for MS/MS data).

EXPERIMENTAL PREREQUISITES FOR CORRECT ANNOTATION

All lipid species and lipid molecular species data presented need information on levels of structural resolution attained by mass spectrometric analysis, and sufficient supplementary data to justify annotation by shorthand notation. At minimum, such data should contain the measured intact *m/z* value, the adduct ion used for identification, the retention time when chromatography is applied, and the measured fragment *m/z* values.

Assignment and therefore use of specific shorthand nomenclature for defined **functional groups** (Table 1 A–C) requires additional techniques. An example is derivatization of hydroxyl groups by trimethylsilylation followed by GC/MS EI and analysis of fragment ions formed. In many cases ESI-MS/MS of underivatized constituent fatty acyls in general leads to specific product ions, if ESI populates a charge site near the functional group (7). Definition of DB positions can be determined by several techniques including ozonolysis during analysis (OzID) (8) or specific adduct formation with acetone in photochemical Paterno-Büchi reaction (9). These reactions can be carried out in shotgun or LC-MS/MS experiments. High energy MS/MS has been used to assign DB position of fairly complex fatty acyls as well as methyl branching (10). Alternatively, GC/MS can be used including specific derivatization of the carboxylate group, to drive specific DB fragmentation in EI spectra (11). Chemical ionization techniques are also useful by application of specific chemical ionization reagent gases to define DB positions (12).

TABLE 1A. Abbreviations of functional groups/side chains

| Functional Group/Side Chain | Abbreviation |
|--|-----------------|
| Ethyl branch | Et |
| Methyl branch | Me |
| Bromo | Br |
| Chloro | Cl |
| Fluoro | F |
| Iodo | I |
| Nitro | NO ₂ |
| Epoxy | Ep |
| Peroxy | OO |
| Methoxy | OMe |
| Alkoxy (ether) | oxy |
| Amino | NH ₂ |
| Hydroperoxy | OOH |
| Sulfanyl | SH |
| hydroxy | OH |
| Oxo (keto/aldehyde; depending on position) | oxo |
| Cyano | CN |
| Phosphate | P |
| Sulfate | S |
| Carboxylic acid | COOH |
| Glycine | G |
| Taurine | T |

The order of functional groups aligns with IUPAC hierarchy (14).

Common names of lipid species, e.g., for certain fatty acids and for oxygenated fatty acids denote a chemically defined structure including stereochemistry. For proper annotations in these cases, the analytical method has to provide for chiral separation of known stereoisomeric compounds. This validation demands data on reproducibility and limit of quantification. Similarly, when novel structures are described, analytical details proving structural details need to accompany the data. Guidelines for method validation and reporting of novel lipid molecules are currently being developed within the Lipidomics Standard Initiative (<https://lipidomics-standards-initiative.org>) as community-wide effort (13).

UPDATES ON GENERAL RULES FOR SHORTHAND NOTATION

Here, we describe updates and rules applicable to all lipid categories described below. This includes rules on the hierarchical concept and application of the nomenclature and annotation of lipid structures as well as on annotation of stable isotope-labeled lipids. Three major updates are:

- The term “DBs” is replaced by “double bond equivalents” (DBEs), because removal of two hydrogen atoms from precursor lipid forms a double bond, an oxo group or a cyclic structure. Frequently, MS does not distinguish between these alternatives.

TABLE 1B. Abbreviations of cyclic structures

| Cyclic Structures | Abbreviation |
|-------------------|--------------|
| Cyclopropyl | cy3 |
| Cyclopropenyl | cy3:1 |
| Cyclobutyl | cy4 |
| Cyclopentyl | cy5 |
| Cyclohexyl | cy6 |

TABLE 1C. Abbreviations of carbohydrate structures

| Carbohydrate Structures | Abbreviation |
|---|--------------|
| Hexose | Hex |
| Galactose | Gal |
| Glucose | Glc |
| Mannose | Man |
| Neuraminic acid | Neu |
| N-acetyl hexosamine | HexNAc |
| N-acetyl galactosamine | GalNAc |
| N-acetyl glucosamine | GlcNAc |
| N-acetyl neuraminic acid | NeuAc |
| N-glycolylneuraminic acid | NeuGc |
| Keto-deoxy-glycero-galacto-nononic acid | Kdn |
| Glucuronic acid | GlcA |
| Xylose | Xyl |
| Fucose | Fuc |

Glycan annotation is based on IUPAC-approved abbreviations (<https://www.ncbi.nlm.nih.gov/glycans/snfg.html>) (15).

- Oxygen atoms represent not only the main component introduced during oxygenation, but occurs also in hydroxy groups as a principal structural feature in many lipid classes such as sphingoid bases. Because hydroxy, oxo or other oxygen functional groups may not be differentiated by high resolution/accurate mass analysis, annotation is done by the number of oxygens linked to the hydrocarbon chain.
- Use of parentheses and brackets is minimized. Parentheses indicate primarily positions and, with regard to functional groups only those with numbers behind them, like (OH)₂, (NO₂), (NH₂). The use of square brackets is restricted to chemical configurations R and S, to stable isotopes, and to the frame of carbons in a ring structure.

Hierarchical concept and application of shorthand notation

- Upon application of a validated MS-method, interpretation of mass spectra by “biological intelligence” and the use of common or trivial names, as alluded to specifically in the introduction, is permissible. Such annotations need to be clearly stated. Examples are ambiguities pertaining to bond type, oxygenated groups, and branched chains.
- “Species level” is now the lowest hierarchical level. It represents the sum composition, i.e., sum of carbon atoms, DBEs, and number of additional oxygen atoms, e.g., FA 18:1;O. It thus replaces former “Lipid class level” mass (i.e., lipid class and the – uncharged - molecular mass). Of note, for sterols, the ABCD ring system is assumed and not expressed as DBE.
- “Phosphate-position level” annotates positions of phosphate group(s), e.g., PIP(3′) or PIP₂(4′,5′) at phosphatidylinositolphosphate.
- “Molecular species level” pertains to all categories addressed here and is reached as soon as constituent fatty acyl/alkyl-residues are identified, e.g., TG 16:0_18:1_18:1, a triglyceride.
- “*sn*-position level” is a more refined level in GL and GP categories, enabling annotation of the *sn*-position of fatty acyl/alkyl constituents at the glycerol backbone as indicated by a slash, e.g., TG 16:0/18:1/18:1.
- “DB-position level” or “DBE-position level” pertain to species having constituents with defined position of double bonds or double bond equivalents, e.g., FA 18:2 (9, 11);O.

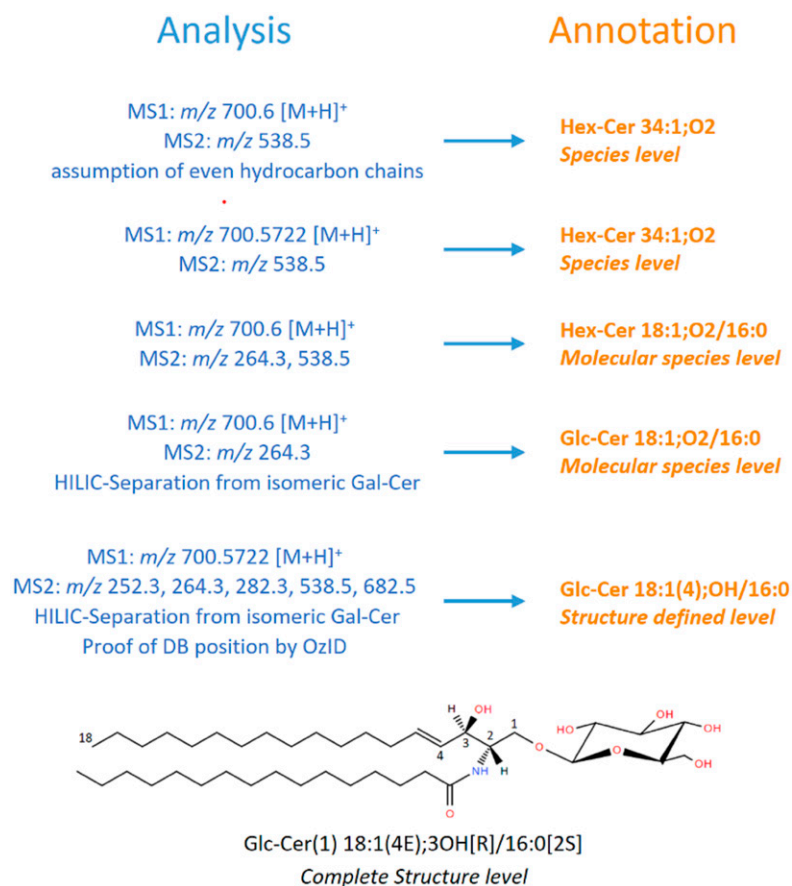


Fig. 1. Hierarchical scheme for the analysis of glucosylceramide. “Analysis” presents MS-data and “Annotation” the respective hierarchical *levels* with corresponding shorthand annotation. The chemical structure illustrates the *Complete Structure level*, numbers along the sphingoid base indicate conventional numbering of carbons therein.

- “Structure defined level” annotates molecular species composed of various constituents and functional groups, yet without positions and stereochemical details, e.g., FA 18:2;OH.
- “Full structure level” annotates molecular species composed of various constituents and functional groups including positions, yet without stereochemical details, e.g., FA 18:2(9Z,11E);13OH.
- “Complete structure level” defines detailed structures of all functional groups including stereochemistry as shown in the LMSD, e.g., 13R-HODE, 13S-HODE (= common name).

Figure 1 presents such a hierarchical scheme, taking the example of glucosylceramide.

A word of caution is appropriate here: Annotations based solely on m/z features and on returns from database retrieval

are frequently incorrect due to over-interpretation of experimental data, i.e., returns of chemically defined lipid molecules at Complete structure level. It is therefore of major importance that database search tools return appropriate annotations based on sum composition, i.e., at Species level and Molecular species level. Such tools are, for example, the LIPID MAPS MS search tools (https://lipidmaps.org/resources/tools/bulk_structure_searches_overview.php) (see also comment in the discussion) or the “ALEX lipid calculator” (<http://alex123.info/ALEX123/MS.php>).

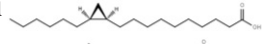

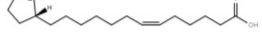
Annotation of lipid structures

- Lipid species are annotated by class shorthand abbreviation (see Tables 2A-6A), followed by a space and C-atoms:DBE, e.g., TG 54:5, or C-atoms:DBE;O-atoms in fatty acyl/alkyl residues, e.g., FA 18:1;O or PC 38:3;O2.

TABLE 2A. Class abbreviations in Category FA

| Common Name | Lipid Class, LIPID MAPS | Abbreviation |
|----------------------|--|--------------|
| Fatty acids | Fatty acids and conjugates [FA01] | FA |
| Fatty alcohols | Fatty alcohols [FA05] | FOH |
| Fatty aldehydes | Fatty aldehydes [FA06] | FAL |
| Acyl carnitines | Fatty acyl carnitines [FA0707] | CAR |
| Acyl CoAs | Fatty acyl CoAs [FA0705] | CoA |
| N-acyl amines | N-acyl amines [FA0802] | NA |
| N-acyl ethanolamines | N-acyl ethanolamines (endocannabinoids) [FA0804] | NAE |
| N-acyl taurines | N-acyl amines [FA0802] | NAT |
| Wax esters | Wax monoesters [FA0701] | WE |
| Wax diesters | Wax diesters [FA0702] | WD |
| FA estolides | FAHFA wax monoesters [FA0701] | FA-EST |

TABLE 2B. Level-dependent shorthand notation for examples of fatty acids

| Subclass | Species Level ^{a,b} | DB-Position Level ^c | Full Structure Level ^d | Complete Structure Level (= Common Name) ^e |
|-------------------|------------------------------|-----------------------------------|--|---|
| Straight-chain FA | FA 12:0 | | | Laurate |
| | FA 14:0 | | | Myristate |
| | FA 16:0 | | | Palmitate |
| | FA 16:1 | FA 16:1 (9) | FA 16:1 (9Z) | Palmitoleate |
| | FA 18:0 | | | Stearate |
| | FA 18:1 | FA 18:1 (9) | FA 18:1 (9Z) | Oleate |
| | FA 18:1 | FA 18:1 (11) | FA 18:1 (11E) | <i>trans</i> -Vaccenate |
| | FA 18:2 | FA 18:2 (9,12) | FA 18:2 (9Z,12Z) | Linoleate |
| | FA 18:3 | FA 18:3 (9,12,15) | FA 18:3 (9Z,12Z,15Z) | α -Linolenate |
| | FA 18:3 | FA 18:3 (6,9,12) | FA 18:3 (6Z,9Z,12Z) | γ -Linolenate |
| | FA 18:4 | FA 18:4 (6,9,12,15) | FA 18:4 (6Z,9Z,12Z,15Z) | Stearidonate |
| | FA 20:0 | | | Arachidate |
| | FA 20:3 | FA 20:3 (8,11,14) | FA 20:3 (8Z,11Z,14Z) | <i>dihomo</i> - γ -Linolenate |
| | FA 20:3 | FA 20:3 (11,14,17) | FA 20:3 (11Z,14Z,17Z) | |
| | FA 20:3 | FA 20:3 (5,8,11) | FA 20:3 (5Z,8Z,11Z) | Mead acid |
| | FA 20:4 | FA 20:4 (5,8,11,14) | FA 20:4 (5Z,8Z,11Z,14Z) | Arachidonate |
| | FA 20:5 | FA 20:5 (5,8,11,14,17) | FA 20:5 (5Z,8Z,11Z,14Z,17Z) | Eicosapentaenoate |
| | FA 22:0 | | | Behenate |
| | FA 22:6 | FA 22:6 (4,7,10,13,16,19) | FA 22:6 (4Z,7Z,10Z,13Z,16Z,19Z) | Docosahexaenoate |
| | FA 24:0 | | | Lignocerate |
| | FA 24:1 | FA 24:1 (15) | FA 24:1 (15Z) | Nervonate |
| | FA 32:5 | FA 32:5 (14,17,20,23,26) | FA 32:5 (14Z,17Z,20Z,23Z,26Z) | Dotriacontapentaenoic acid; FA 32:5 (n-6) |
| | FA 34:5 | FA 34:5 (19,22,25,28,31) | FA 34:5 (19Z,22Z,25Z,28Z,31Z) | Tetracontapentaenoic acid; FA 34:5 (n-3) |
| FA 36:6 | FA 36:6 (18,21,24,27,30,33) | FA 36:6 (18Z,21Z,24Z,27Z,30Z,33Z) | Hexatriacontahexaenoic acid; FA 36:6 (n-3) | |
| Fatty acyl ester | FA 19:0 | FA 18:0;1OMe | Methyl stearate | |
| Methyl branched | FA 20:0 | FA 16:0;3Me,7Me,11Me,15Me | FA 16:0;3Me[R],11Me[R],15Me (Phytanate) | |
| Hydroxy | FA 18:0;O | FA 18:0;9OH | FA 18:0;9OH[S] | |
| Oxo | FA 11:1;O ^b | FA 11:0;9oxo | FA 11:0;9oxo | |
| Cyclopropane | FA 19:1 | FA 19:0;[11-13cy3:0] | Lactobacillic acid  | |
| Cyclopropene | FA 19:2 | FA 19:0;[9-11cy3:1 (9)] | Sterculic acid  | |
| Cyclopentene | FA 18:3 | FA 18:1 (6Z);[14-18cy5:1 (15)] | Gorlic acid  | |

^aUncharged molecular mass measured by low resolution MS of corresponding *m/z* from carboxylate anion (electrospray ionization) or molecular ion species (radical cation by EI).

^bAnnotation based on the assumption of a straight-chain fatty acyl plus functional groups based on exact mass measurements using a high-resolution mass spectrometer of fatty acyl indicating ion.

^cPositions of DBs determined by independent techniques such as ozonolysis (8) or photochemical derivatization (9).

^dShorthand notation applies only when exact location and nature of functional group(s) are determined by specific fragment ions obtained by derivatization and GC/MS or specific product ions in a MS/MS experiment.

^eValidated assay is required to employ trivial names that engages appropriate internal standard, proper assessment of signal-to-noise, and a chromatographic based separation of potential isomers (GC or HPLC).

- Variable constituents like fatty acyls/alkyls are assigned based on their mass as number of C-atoms and number of DBE (C-atoms:DBE), when experimental proof for DB is provided the annotation is C-atoms:DB. Where applicable, the number of oxygen-atoms is added, separated by a semi-colon, e.g., C-atoms:DBE;O-atoms.
- DB-position is indicated by a number according to Δ -nomenclature (geometry unknown) or a number followed by geometry (Z for *cis*, E for *trans*). Specific techniques are required for determination of DB-position (or geometry) to validly use this level of annotation, e.g., FA 18:2 (9, 12), FA 18:2(9Z,12Z).
- Positions for all functional groups are stated in front of functional group abbreviation, e.g., FA 20:4;12OH.
- Generally, all functional groups (see Table 1A for abbreviations) are separated by a **semicolon** after the number of DBE. Functional groups are placed **inside a separate pair of parentheses, only** if more than one followed by the number of groups, e.g., FA 20:3;(OH)2; oxo. Moreover, functional groups containing numbers such as NO₂ or NH₂ are generally placed inside a separate pair of parentheses, e.g., FA 18:1;(NO₂).

The order of functional groups follows the IUPAC hierarchy (14).

- Except for DBE/DB-position, **proven** positions of all other functional groups are stated according to Δ -nomenclature in front of the functional group abbreviation that are separated by a comma if more than one, e.g., FA 20:3(5Z,13E);11OH,15OH;9oxo
- Cyclic structures cyX (X = number of ring atoms, see Table 1B for abbreviations) are presented in front of other functional groups. Their structural details are annotated within a pair of square brackets. Within the square brackets the positions of ring atoms, separated by hyphen, are placed in front of the cyX annotation. Other functional groups are placed after the ring structure of the cyX annotation, e.g., FA 20:2;[8-12cy5;11OH;9oxo];15OH = 8-iso-PGE₂ or PGE₂.
- Carbohydrate structures (Table 1C), e.g., in complex glycosphingolipids, are annotated as described for glycans (<https://www.ncbi.nlm.nih.gov/glycans>) (15). When the sequence of sugars components is known they are shown in this order separated by a hyphen, e.g., Gal-Glc-Cer 18:1; O2/16:0. In case the sequence is unknown the components

TABLE 2C. Level-dependent shorthand notation for examples of fatty aldehydes, esters, and amides

| Subclass | Species Level | Molecular Species Level | DB-Position Level ^a | Full Structure Level ^b | Complete Structure Level (= Common Name) ^c |
|---|----------------------|----------------------------|----------------------------------|---|---|
| Fatty aldehyde Wax ester ^d | FAL 9:1;O WE 32:1 | FAL 9:1;O WE 14:0/18:1 | FAL 9:1(2);OH WE 14:0/18:1(9) | FAL 9:1(2E);4OH WE 14:0/18:1(9Z) | 4-Hydroxynonal WE 14:0/18:1(9Z) |
| Alkyl acetates ^d | WE 20:3 | WE 18:3/2:0 | WE 18:3 (9,12,15)/2:0 | WE 18:3 (9Z,12Z,15Z)/2:0 | WE 18:3(9Z,12Z,15Z)/2:0 |
| Wax diester ^d | WD 42:0 | WD 22:0/FA 10:0_FA 10:0 | WD 22:0/FA 10:0_FA 10:0 | WD 22:0; 2O(FA 10:0), 3O(FA 10:0) | WD 22:0;2O(FA 10:0[S]),3O(FA 10:0[R]) |
| N-acyl amines (NA) ^d | NA 24:4 | NA 4:0/20:4 | NA 4:0/20:4 (5,8,11,14) | NA 4:0/20:4 (5Z,8Z,11Z,14Z) | NA 4:0/20:4(5Z,8Z,11Z,14Z) |
| N-acyl ethanolamines (NAE) ^d | NAE 18:2 | NAE 18:2 | NAE 18:2(9,12) | NAE 18:2(9Z,12Z) | NAE 18:2(9Z,12Z), anandamide 18:2(n-6) |
| Fatty acyl estolides (FA-EST) | FAHFA 36:1;O | FAHFA 18:1/18:0;O | FAHFA 18:1(9)/ 18:0;O | FAHFA 18:1(9Z)/9O (FA 18:0) | FAHFA 18:1(9Z)/9O(FA 18:0[R]) |

^a Positions of DBs determined by independent techniques such as ozonolysis (8) or photochemical derivatization (9).

^b Shorthand notation applies only when exact location and nature of functional group(s) are determined by specific fragment ions obtained by derivatization and GC/MS or specific product ions in a MS/MS experiment.

^c Validated assay is required to employ trivial names that engages appropriate internal standard, proper assessment of signal-to-noise, and a chromatographic based separation of potential isomers (GC or HPLC).

^d In shorthand notation for wax monoesters (WE), wax diesters (WD), and fatty amides (NA, NAE), alcohol and amine moieties precede the fatty acyl moiety.

(followed by their number if more than one) are shown in alphabetic order in front of the respective lipid backbone, e.g., Gal2GlcCer 18:1;O2/16:0.

- **Acyl-linkages** (*N*- and/or *O*-) are annotated by FA C-atoms:DBE inside a separate pair of parentheses with proven position in front, e.g., Cer 18:1;O2/26:0;26O(FA 18:2).
- **Alkyl-linkages** (*N*- and/or *O*-) are annotated by C-atoms:DBE inside a separate pair of parentheses with proven position in front, e.g., FA 18:1(12Z);9O(16:1) for an ether lipid.
- When functional groups are part of lipid class abbreviation, e.g., PIP2 or SPBP, their proven positions are shown inside parentheses, separated by a comma if more than one, e.g., PIP2(4',5') 38:4 or SPBP (1) 18:1;O2.
- Greek letters are transcribed to Latin letters as follows: α to a, β to b, γ to g, δ to d, ω to w.
- Proven stereochemistry is shown after the respective functional group/side chain in square brackets [R] or [S], e.g., FA 20:4(6Z,8E,10E,14Z);5OH[S],12OH[R] = LTB₄.

Annotation of isotope-labeled lipids

- Isotope-containing lipid structures are indicated in square brackets annotating the isotope, followed by the number of isotopic atoms, e.g., FA 18:1[13C5].
- Multiple isotopes are separated by a comma, e.g., FA 18:1[13C5,D4].

- When positions of isotopes are known, they are indicated in a separate pair of parentheses in front of the isotope number, e.g., FA 18:1[(14,15,16,17,18)13C5].
- Isotopes in fatty acyls or alkyls and in sphingoid bases are indicated in square brackets after the number of DBE, e.g., PC 34:1[D9] or PC O-16:0_18:1[13C5] and in Cer 34:1;O2[13C3], respectively. Isotopes in head groups of these structures are indicated in square brackets after class shorthand abbreviation, e.g., PC[D9] 34:1, TG[13C3] 54:3, SM[D9] 34:1;O2.
- When positions of isotopes in the lipid are not known, they are indicated in square brackets in front of class shorthand abbreviation, e.g., [D5]PC 34:1, [13C7]TG 54:3.

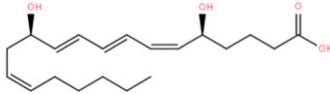
FATTY ACYLS (FA)

Fatty acyls

Shorthand abbreviations for Fatty Acyl classes are stated in **Table 2A**.

Table 2B shows that lowest resolution level is based on *m/z* values, i.e., annotation at Species level (low mass resolution MS, e.g., carboxylate anion and oxygen atoms from functional groups). In addition, it is assumed that only a straight-chain fatty acid with or without DBE(s) is present. High mass resolution with accurate mass measurements may identify additional elements such as oxygen atoms of

TABLE 2D. Shorthand notations for acyclic oxylipins at appropriate levels of annotation in lipidomic studies

| Species Level ^{a,b} | DB-Position Level ^c | Structure Defined Level | Full Structure Level ^d | Complete Structure Level (= Common Name) ^{e,f} |
|------------------------------|--------------------------------|-------------------------|--|---|
| FA 18:2;O | FA 18:2(9,11);O | FA 18:2;OH | FA 18:2(9Z,11E);13OH | 13R-HODE, 13S-HODE |
| FA 20:4;O | FA 20:4(6,8,11,14);O | FA 20:4;OH | FA 20:4(6E,8Z,11Z,14Z);5OH | 5R-HETE, 5S-HETE |
| FA 20:4;O | FA 20:4(5,8,10,14);O | FA 20:4;OH | FA 20:4(5Z,8Z,10E,14Z);12OH | 12R-HETE, 12S-HETE |
| FA 20:4;O | FA 20:4(5,8,11,13);O | FA 20:4;OH | FA 20:4(5Z,8Z,11Z,13E);15OH | 15R-HETE, 15S-HETE |
| FA 20:4;O2 | FA 20:4(6,8,10,14);O2 | FA 20:4;(OH)2 | FA 20:4(6Z,8E,10E,14Z);5OH,12OH | LTB ₄ (5S,12R) |
| | | | |  |
| FA 20:5;O3 | FA 20:5(6,8,11,14,16);O3 | FA 20:5;OOH;OH | FA 20:5(6E,8Z,11Z,14Z,16E);5OOH;18OH | 5S-Hp-18S-HEPE |
| FA 20:5;O3 | FA 20:5(6,8,10,14,16);O3 | FA 20:5;(OH)3 | FA 20:5(6Z,8E,10E,14Z,16E);5OH,12OH,18OH | Resolvin E1 (5S,12R,18R) |
| FA 22:6;O3 | FA 22:6(4,8,10,12,14,19);O3 | FA 22:6;(OH)3 | FA 22:6(4Z,8E,10Z,12E,14E,19Z);7OH,16OH,17OH | Resolvin D2 (7S,16R,17S) |
| FA 22:6;O2 | FA 22:6(4,8,10,12,16,19);O2 | FA 22:6;(OH)2 | FA 22:6(4Z,8E,10E,16Z,19Z);7OH,14OH | Maresin 1 (7R,14S) |

^aUncharged molecular mass measured by low resolution MS of corresponding *m/z* from carboxylate anion (electrospray ionization) or molecular ion species (radical cation by EI).

^bAnnotation based on the assumption of a straight-chain fatty acyl plus functional groups based on exact mass measurements using a high-resolution mass spectrometer of fatty acyl indicating ion.

^cPositions of DBs determined by independent techniques such as ozonolysis (8) or photochemical derivatization (9).

^dShorthand notation applies only when exact location and nature of functional group(s) are determined by specific fragment ions obtained by derivatization and GC/MS or specific product ions in a MS/MS experiment.

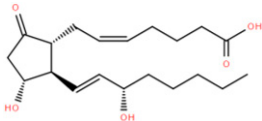
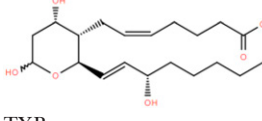
^eCommon shorthand accepted by IUPAC (23).

^fValidated assay is required to employ trivial names that engages appropriate internal standard, proper assessment of signal-to-noise, and a chromatographic based separation of potential isomers (GC or HPLC).

functional groups. Thus, a limited amount of structural information is provided at this level of analysis following the rules alluded to in the Annotation of lipid structures section, i.e., Species level. Annotation at DB-position level requires techniques such as ozonolysis (8) or photochemical derivatization (9) or GC-MS. The use of trivial or common names for even *simple* fatty acids implies that additional methods have been used to define the exact

structure, such as a straight-chain, positions of DBs, or DB geometries. Chiral chromatography preceding MS/MS is required for respective stereochemistry. Because this is generally not routinely done, investigators should note in their reports when using a common name for a fatty acid that "The identity and stereochemistry of the fatty acid species reported using a common name (e.g., oleic acid, linolenic acid, arachidonic acid, etc.) is assumed based on

TABLE 2E. Shorthand notations for cyclic oxylipins at appropriate levels of annotation in lipidomic studies

| Species Level ^{a,b} | Structure Defined Level | Full Structure Level ^c | Complete Structure Level (= Common Name) ^{d,e} |
|------------------------------|-------------------------|--|---|
| FA 20:4;O3 | FA 20:3;(OH)2;oxo | FA 20:2(5Z,13E);[8-12cy5;11OH;9oxo];15OH |  PGE ₂ PGD ₂ PGF _{2α} 8-iso-PGE ₁ 6-oxo-PGF _{1α} |
| FA 20:4;O3 | FA 20:3;(OH)2;oxo | FA 20:2(5Z,13E);[8-12cy5;9OH;11oxo];15OH |  TXB ₂ 20-F4-NeuroP |
| FA 20:3;O3 | FA 20:3;(OH)3 | FA 20:2(5Z,13E);[8-12cy5;9OH;11OH];15OH | |
| FA 20:3;O3 | FA 20:2;(OH)2;oxo | FA 20:1(13E);[8-12cy5;11OH;9oxo];15OH | |
| FA 20:3;O4 | FA 20:2;(OH)3;oxo | FA 20:1(13E);[8-12cy5;9OH;11OH];15OH;6oxo | |
| FA 20:3;O4 | FA 20:3;(OH)3;oxy | FA 20:2(5Z,13E);[8-13cy6;9OH;11OH];11oxy;15OH | |
| FA 22:5;O3 | FA 22:5;(OH)3 | FA 22:4(4Z,7Z,10Z,18E);[13-17cy5;14OH,16OH];20OH | |

^aUncharged molecular mass measured by low resolution MS of corresponding *m/z* from carboxylate anion (electrospray ionization) or molecular ion species (radical cation by EI).

^bAnnotation based on the assumption of a straight-chain fatty acyl plus functional groups based on exact mass measurements using a high-resolution mass spectrometer of fatty acyl indicating ion.

^cShorthand notation applies only when exact location and nature of functional group(s) are determined by specific fragment ions obtained by derivatization and GC/MS or specific product ions in a MS/MS experiment.

^dCommon shorthand accepted by IUPAC (23).

^eValidated assay is required to employ trivial names that engages appropriate internal standard, proper assessment of signal-to-noise, and a chromatographic based separation of potential isomers (GC or HPLC).

TABLE 2F. Parent polyunsaturated fatty acids and oxygenated product specialized pro-resolving mediators

| Fatty Acid | Product Class | Complete Structure Level (= Common Name) |
|---|---------------------|---|
| Arachidonic acid; AA(n-6) | Eicosanoid | Lipoxin A4, lipoxin B4 |
| Eicosapentaenoic acid; EPA(n-3) | Eicosanoid | Resolvin E1, E2, E3 |
| Docosahexaenoic acid; DHA(n-3) | Docosanoid | Resolvin D1, D2, D3, D4, D5, D6 |
| Docosapentaenoic acid; DPA(n-3) | Docosanoid | Resolvin T1, T2, T3, T4 |
| Docosahexaenoic acid; DHA(n-3) | Docosanoid | PCTR1, PCTR2, PCTR3, protectin D1/ neuroprotectin D1 |
| Docosahexaenoic acid; DHA(n-3) | Docosanoid | MCTR1, 2, 3, maresins 1, 2 |
| Docosahexaenoic acid; DHA(n-3) | Docosanoid | Protectin DX |
| Dotriacontahexaenoic acid; FA 32:6(n-3) | Dotriacontanoid | Elovanoid ELV-N32 |
| Tetraatriacontahexaenoic acid; FA 34:6(n-3) | Tetraatriacontanoid | Elovanoid ELV-N34 |

biological intelligence". This comment applies to *simple* as well as *complex* lipids that include fatty acids as part of the structure (e.g., glycerophospholipids, triacylglycerols, etc.). Examples for shorthand notation of fatty acids are presented in Table 2B.

Fatty acyl esters, i.e., wax esters (WEs), wax diesters (WDs), fatty acyl estolides (FAHFAs, FA-EST), as well as *N*-acyl amines (NAs) and *N*-acyl ethanolamines (NAEs) are shown in Table 2C.

Oxygenated fatty acyls

Lipidomic studies of "oxygenated fatty acyls," commonly referred to as "oxylipins" or "oxygenated PUFAs" in the literature, involves analysis of enzymatically and nonenzymatically generated lipids such as octadecanoids, eicosanoids, docosanoids, do- and tetraatriacontanoids (Table 2D–F). Enzymatically generated isomers include prostaglandins, leukotrienes, and the various "specialized pro-resolving mediators," i.e., lipoxins, protectins, maresins, and resolvin D/Es (Table 2F) (16). Nonenzymatic oxygenation of polyunsaturated fatty acids leads to numerous cyclic structures with various stereochemistry, such as phytoprostanes, isoprostanes, neuroprostanes, and all families of furans. Some of these isoprostanoids were identified over 25 years ago, particularly those of mammalian origin (17) and more recently also as components in foods of plant origin (18). The nomenclature for isoprostanoids is based on Taber, Morrow, and Roberts (19) and Rokach et al. (20), an update appeared in 2010 (21). Table 2G presents the precursor-product relationships for the classes of phytoprostanes, isoprostanes,

and neuroprostanes, for which abbreviations PhytoP, IsoP, and NeuroP, respectively, have been proposed.

Standards for structural validation by MS-inspection of these oxygenated fatty acids are described by Galano et al. (17) and are in agreement with those referred to for oxylipins (22). Specific shorthand nomenclature has been previously suggested and widely used for polyunsaturated oxygenated fatty acids (23).

The use of a common name (Table 2B, D, E) for fatty acyls or in reporting lipidomic studies also requires a high level of validation, typically with a representative biological sample using, for example, stable isotope dilution and chiral LC-MS/MS or capillary GC/MS with highly reproducible retention times for authentic standards. Otherwise, assumptions made on the basis of biological intelligence must be clearly stated.

GLYCEROLIPIDS (GL)

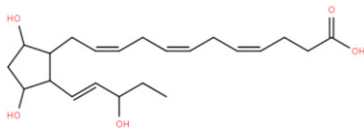
See **Table 3A** and **B** for class abbreviations and examples, respectively. Lipid class abbreviation followed by number of C-atoms:number of DBE, for oxygenated lipids C-atoms:DBE;O-atoms, are as described in the Annotation of lipid structures section.

Glycerolipids with known fatty acyl/alkyl constituents (molecular species):

- **separator** _: *sn*-position of acyl/alkyl constituents is **not known**. Constituents are presented in the order of increasing number of C-atoms, as are DB (DBE)-numbers for each C-atom number, e.g., TG 16:0_18:1_18:3.

TABLE 2G. Parent polyunsaturated fatty acids and oxygenated product isoprostanooids

| Fatty Acid | Product Class | Complete Structure Level (= Common Name) |
|------------------------------------|---------------|--|
| α -Linoleic acid; ALA(n-3) | Octadecanoid | F1-PhytoP |
| γ -Linolenic acid; GLA(n-6) | Octadecanoid | F1-PhytoP _{GLA} |
| Arachidonic acid; AA(n-6) | Eicosanoid | F2-IsoP |
| Eicosapentaenoic acid; EPA(n-3) | Eicosanoid | F3-IsoP |
| Adrenic acid; AdA(n-6) | Docosanoid | F2-IsoP _{AdA} |
| Docosapentaenoic acid; DPA(n-6) | Docosanoid | F3-NeuroP _{DPA(n-6)} |
| Docosapentaenoic acid; DPA(n-3) | Docosanoid | F3-NeuroP _{DPA(n-3)} |
| Docosahexaenoic acid; DHA(n-3) | Docosanoid | F4-NeuroP |



FA 22:4(4Z,7Z,10Z,18E);[13-17cy5;14OH,16OH];20OH

TABLE 3A. Class abbreviations in Category GL

| Common Name | Lipid Class, LIPID MAPS | Abbreviation |
|---|------------------------------------|--------------|
| Monoacyl/alkylglycerides (monoglycerides) | Monoradylglycerols [GL01] | MG |
| Diacyl/alkylglycerides (diglycerides) | Diradylglycerols [GL02] | DG |
| Triacyl/alkylglycerides (triglycerides) | Triradylglycerols [GL03] | TG |
| Estolides | Estolides [GL0305] | TG-EST |
| Sulfoquinovosylmonoacylglycerols | Glycosylmonoacylglycerols [GL0401] | SQMG |
| Monogalactosylmonoacylglycerol | Glycosylmonoacylglycerols [GL0401] | MGMG |
| Digalactosylmonoacylglycerol | Glycosylmonoacylglycerols [GL0401] | DGMG |
| Sulfoquinovosyldiacylglycerols | Glycosyldiacylglycerols [GL0501] | SQDG |
| Monogalactosyldiacylglycerol | Glycosyldiacylglycerols [GL0501] | MGDG |
| Digalactosyldiacylglycerol | Glycosyldiacylglycerols [GL0501] | DGDG |

- **separator** /: *sn*-position of acyl/alkyl constituents is **proven** (order *sn*-1/*sn*-2/*sn*-3; no FA linked 0:0), e.g., TG 16:0/18:3/18:1.
- When only one acyl chain of TG is known, it is presented in front of the sum of the remaining two acyl residues, e.g., TG 16:0_36:3.
- When only one of the *sn*-positions is defined, this is indicated inside a pair of parentheses, e.g., TG 16:0_18:1 (*sn*-2)_18:0.

Other bond types than ester bonds are indicated as follows in front of the sum of C-atoms for acyl/alkyl constituents:

- O = alkyl, e.g., TG O-52:3
- P = proven O-alk-1-enyl-bond (acid-sensitive ether bond in “neutral plasmalogens” is *not* counted as a DB/DBE within the acyl-chain), e.g., TG P-52:3 or at higher resolution TG P-16:0/18:3/18:1.
- More than one “non”-ester bond is indicated in front of the bond type as d for *di*, t for *tri*, and e for *tetra*.

GLYCEROPHOSPHOLIPIDS (GP)

See **Table 4A–C** for abbreviations and examples. Short-hand notation for phospholipid species contains abbreviation for phospholipid classes, followed by number of C-atoms:number of DBE, i.e., PS 36:4, for oxygenated lipids C-atoms:DBE;O-atoms, i.e., PS 36:3;O, as described in the Annotation of lipid structures section.

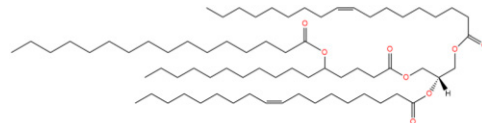
Phospholipids (PLs) and Lysophospholipids (LPLs)

Molecular species of phospholipids with known fatty acyl/alkyl constituents (Table 4B):

- **separator** _: *sn*-position of acyl/alkyl constituents is **not known**. Order of constituent presentation as described for glycerolipids, e.g., PC 16:0_18:2.
- **separator** /: *sn*-position of acyl/alkyl constituents is **proven** (*sn*-1/*sn*-2 or *sn*-2/*sn*-3); no constituent 0:0; e.g., PC 16:0/18:2.
- For BMP and CL classes *sn*-position order will be *sn*-2/*sn*-3/*sn*-2’/*sn*-3’ and *sn*-1/*sn*-2/*sn*-1’/*sn*-2’, respectively.

TABLE 3B. Examples for shorthand notation of glycerolipids

| Bond Type | Species Level ^a | Molecular Species Level ^b | <i>sn</i> -Position Level ^c | Full Structure Level ^d |
|--------------|----------------------------|---|---|---------------------------------------|
| Acyl | MG 18:0 | MG 18:0 | MG 0:0/18:0/0:0 | |
| Alkyl | MG O-18:0 | MG O-18:0 | MG 0:0/O-18:0/0:0 | |
| Diacyl | DG 34:1 | DG 16:0_18:1 | DG 16:0/18:1/0:0 | DG 16:0/18:1(9Z)/0:0 |
| Acyl-alkyl | DG O-34:1 | DG O-16:0_18:1 | DG O-16:0/18:1/0:0 | DG O-16:0/18:1(9Z)/0:0 |
| Dialkyl | DG dO-32:1 | DG O-16:0_O-16:1 | DG O-16:0/O-16:1/0:0 | DG O-16:0/O-16:1(9Z)/0:0 |
| | DG 30:1 ^e | | | |
| Triacyl | TG 52:2 | TG 16:0_18:1_18:1 | TG 16:0/18:1/18:1 | TG 16:0/18:1(9Z)/18:1(11Z) |
| | | TG 16:0_36:2 (only one acyl chain identified) | TG 16:0_18:1(<i>sn</i> -2)_18:1 ^f | |
| Acyl-alkyl | TG O-52:2 | TG O-16:0_18:1_18:1 | TG O-16:0/18:1/18:1 | TG O-16:0/18:1(9Z)/18:1(11Z) |
| | TG 51:2 ^e | | | |
| Acyl-dialkyl | TG dO-52:2 | TG O-18:1_O-16:0_18:1 | TG O-18:1/O-16:0/18:1 | TG O-18:1(9Z)/O-16:0/18:1(9Z) |
| | TG 50:2 ^e | | | |
| Trialkyl | TG tO-52:2 | TG O-18:1_O-16:0_O-18:1 | TG O-18:1/O-16:0/O-18:1 | TG O-18:1(9Z)/O-16:0/O-18:1(9Z) |
| | TG 49:2 ^e | | | |
| TG-Estolide | TG 68:3;O2 | TG 18:1_18:1_32:1;O2 | TG 16:0;O(FA 16:0)/18:1/18:1 | TG 16:0;5O(FA 16:0)/18:1(9Z)/18:1(9Z) |



^a Annotation based on exact mass measurements using a high-resolution mass spectrometer, which allows differentiation of isobaric acyl and alkyl species.

^b Annotation requires MS/MS and detection of FA chain-specific fragments.

^c *sn*-Positions determined by specific analysis like differential mobility spectrometry (32), LC separation of isomeric species using silver ions (33).

^d DB-positions determined by independent techniques such as ozonolysis (8) or photochemical derivatization (9).

^e Annotation using low-resolution MS including the assumption of acyl chains only.

^f Only acyl-chain at *sn*-2-position is defined.

TABLE 4A. Class abbreviations in Category GP

| Common Name | Lipid Class, LIPID MAPS | Abbreviation |
|---|---|--------------|
| Bis[monoacylglycero]phosphates | Monoacylglycerophosphomonoradylglycerols [GP0410] | BMP |
| Cardiolipins | Glycerophosphoglycerophosphoglycerols [GP12] | CL |
| Phosphatidic acids | Glycerophosphates [GP10] | PA |
| Phosphatidylcholines | Glycerophosphocholines [GP01] | PC |
| Phosphatidylethanolamines | Glycerophosphoethanolamines [GP02] | PE |
| Phosphatidylglycerols | Glycerophosphoglycerols [GP04] | PG |
| Phosphatidylglycerolphosphates | Glycerophosphoglycerophosphates [GP05] | PGP |
| Phosphatidylinositols | Glycerophosphoinositols [GP06] | PI |
| Phosphatidylserines | Glycerophosphoserines [GP03] | PS |
| Lysophospholipids | | Prefix L |
| Phosphatidylinositol-mannoside | | PIM |
| Subclasses phosphatidylinositol phosphates | | |
| Phosphatidylinositol-monophosphates | Glycerophosphoinositol monophosphates [GP07] | PIP |
| Phosphatidylinositol-3-phosphates | Glycerophosphoinositol monophosphates [GP07] | PIP(3') |
| Phosphatidylinositol-4-phosphates | Glycerophosphoinositol monophosphates [GP07] | PIP(4') |
| Phosphatidylinositol-5-phosphates | Glycerophosphoinositol monophosphates [GP07] | PIP(5') |
| Phosphatidylinositol-bisphosphates | Glycerophosphoinositol bisphosphates [GP08] | PIP2 |
| Phosphatidylinositol-3,4-bisphosphates | Glycerophosphoinositol bisphosphates [GP08] | PIP2(3',4') |
| Phosphatidylinositol-3,5-bisphosphates | Glycerophosphoinositol bisphosphates [GP08] | PIP2(3',5') |
| Phosphatidylinositol-4,5-bisphosphates | Glycerophosphoinositol bisphosphates [GP08] | PIP2(4',5') |
| Phosphatidylinositol-trisphosphates | Glycerophosphoinositol trisphosphates [GP09] | PIP3 |
| <i>N</i> -modified phospholipids | | |
| <i>N</i> -alkyl PS | | PS-N(Alk) |
| <i>N</i> -acyl PS | | PS-N(FA) |
| Phosphatidylserine-carboxyalkylpyrroles | | PS-CAP |
| Phosphatidylserine-malondialdehydes | | PS-MDA |
| <i>N</i> -alkyl PE | | PE-N(Alk) |
| <i>N</i> -acyl PE | | PE-N(FA) |
| Phosphatidylethanolamine-carboxyalkylpyrroles | | PE-CAP |
| Phosphatidylethanolamine-glucosides | | PE-Glc |
| Phosphatidylethanolamine-glucuronides | | PE-GlcA |
| Phosphatidylethanolamine- α -ketoglucoside | | PE-GlcK |
| Phosphatidylethanolamine-carboxymethylates | | PE-CM |
| Phosphatidylethanolamine-carboxyethylates | | PE-CE |
| Phosphatidylethanolamine-formamides | | PE-FA |
| Phosphatidylethanolamine-carbamides | | PE-CA |
| Phosphatidylethanolamine-malondialdehydes | | PE-MDA |
| Phosphatidylethanolamine-hydroxynonenals | | PE-HNE |
| Phosphatidylethanolamine-isolevuglandins | | PE-isoLG |

- When only one acyl chain or DG moieties of CL are known, sum of acyl residues are presented, e.g., CL 16:0_54:3 and CL 34:1_36:2, respectively.

Lysophospholipid classes are abbreviated as stated in LIPID MAPS nomenclature (Table 4A). Molecular species with unknown *sn*-position are presented as, e.g., LPE 18:1, with known *sn*-position as LPE 18:1/0:0 (Table 4B).

Other bond types than ester bonds are indicated as described for Glycerolipids, e.g., for an ether phospholipid PE O-18:0/18:2, for a “plasmalogen” PE P-18:0/20:4.

Phosphatidylinositol phosphates (PIPs)

It is described in the Annotation of lipid structures section, when functional groups are part of lipid class abbreviation, their proven positions are shown directly at the abbreviation's end inside parentheses, separated by a comma if more than one. A prominent example is PIP3(3',4',5'). Table 4C shows that “Phosphate position level” identifies phosphate position at inositol ring, i.e., PIP(3') 38:4, otherwise it would be PIP 38:4. For ease of handling by databases, numbers of phosphates are not written in lower case.

N-modified phospholipids and lysophospholipids

The amino function in PSs and PEs, including their lysoforms, is prone to react with a variety of electrophiles as has been shown in recent years (24). The products are generally termed *N*-mod PL and *N*-mod LPL in abbreviated form, common names and respective abbreviations are shown in Table 4A. Structures at Species-, Molecular species-, and *sn*-Position levels are presented in shorthand notation as described in the Annotation of lipid structures, Glycerolipids (GL), and Glycerophospholipids (GP) sections; specific examples are shown in Table 4D.

OxPLs

Phospholipids containing PUFA-constituents having methylene-interrupted *cis*-DBs (allylic DBs) and/or polar headgroups having amino-residues are susceptible to oxidation with formation of OxPLs. OxPL, so far, is a general term for a class of lipids produced by several processes that most often cannot be distinguished by MS analysis of the products. In all these cases, the products are called **OxPLs** (25).

TABLE 4B. Examples for shorthand notation of phospho- and lysophospholipids containing ester and/or ether bonds

| Bond Type | Species Level ^a | Molecular SPECIES Level ^b | <i>sn</i> -Position Level ^c | Full Structure Level ^d |
|-------------|----------------------------|--|--|--|
| Diacyl | BMP 34:1 | BMP 16:0_18:1 | BMP 16:0/0:0/18:1/0:0 <i>sn</i> -2/ <i>sn</i> -3/ <i>sn</i> -2'/ <i>sn</i> -3' | BMP 16:0/0:0/18:1(9Z)/0:0 <i>sn</i> -2/ <i>sn</i> -3/ <i>sn</i> -2'/ <i>sn</i> -3' |
| Tetraacyl | CL 72:7 | CL 18:1_18:2_18:2_18:2 CL 18:1_54:6 (only one acyl chain identified) CL 36:3_36:4 (known DG fragments) | CL 18:1/18:2/18:2/18:2 <i>sn</i> -1/ <i>sn</i> -2/ <i>sn</i> -1'/ <i>sn</i> -2' | CL 18:1(9Z)/18:2(9Z,12Z)/18:2(9Z,12Z)18:2(9Z,12Z) <i>sn</i> -1/ <i>sn</i> -2/ <i>sn</i> -1'/ <i>sn</i> -2' |
| Tetra-alkyl | CL eO-80:0 | CL O-20:0/O-20:0/ O-20:0/O-20:0 | CL O-20:0/O-20:0/ O-20:0/O-20:0 | CL O-16:0(3Me,7Me,11Me,15Me)/O-16:0(3Me,7Me,11Me, 15Me)/O-16:0(3Me,7Me,11Me,15Me)/O-16:0(3Me,7Me, 11Me,15Me) |
| Diacyl | PC 34:1 ^e | PC 16:0_18:1 | PC 16:0/18:1 | PC 16:0/18:1(9Z) |
| Alkyl | PC O-34:1 ^e | PC O-16:0_18:1 | PC O-16:0/18:1 | PC O-16:0/18:1(9Z) |
| Dialkyl | PC dO-34:1 | PC O-16:0_O-18:1 | PC O-16:0/O-18:1 | PC O-16:0/O-18:1(9Z) |
| Diacyl | PE 34:1 ^f | PE 16:0_18:1 | PE 16:0/18:1 | PE 16:0/18:1(9Z) |
| Plasmalogen | PE O-34:2 ^f | | PE P-16:0/18:1 ^g | PE P-16:0/18:1(9Z) |
| Triacyl | LCL 54:5 | LCL 18:1_18:2_18:2 | LCL 18:1/18:2/18:2/0:0 | LCL 18:1(9Z)/18:2(9Z,12Z)/18:2(9Z,12Z)/0:0 |
| Monoacyl | LPC 16:0 ^e | LPC 16:0 | LPC 16:0/0:0 | LPC 16:0/0:0 |
| Monoalkyl | LPC O-16:0 ^e | LPC O-16:0 | LPC O-16:0/0:0 | LPC O-16:0/0:0 |

^a Annotation based on exact mass measurements using a high-resolution mass spectrometer, which allows differentiation of isobaric acyl and alkyl species.

^b Annotation requires MS/MS and detection of FA chain specific fragments.

^c *sn*-Positions determined by specific MS analysis like differential mobility spectrometry (34).

^d Positions of DBs determined by independent techniques such as ozonolysis (8) or photochemical derivatization (9).

^e Annotation using low resolution MS, QQQ and +PIS *m/z* 184 requires the assumption of even numbered carbon chains only.

^f Annotation using low resolution MS, QQQ and +NL 141 requires the assumption of even numbered carbon chains only.

^g Identification of plasmalogens (alk-1-enyl bond) require specific MS analysis (35).

Respective modes for production are the following:

- Oxygenation of PL to produce OxPL by direct action of lipoxygenases on PUFA constituents of PL gives rise to enzymatically produced specific oxPL. The stereochemistry of the resulting PUFA component usually reflects the specificity of the specific enzyme involved (26).
- The Land's cycle is an alternative mechanism for enzymatic OxPL formation. Free, unesterified PUFAs liberated by phospholipase A₂ and other enzymatic pathways from PL are first oxygenated by lipoxygenases, cyclooxygenases

or CYP450 oxygenases. The resulting oxygenated PUFAs can then be reesterified into PLs resulting in the indirect enzymatic formation of specific oxPL.

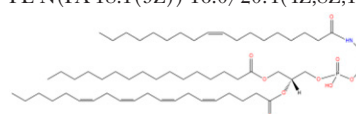
- Nonenzymatic reactions are induced by free-radical oxygen/nitrogen species reacting directly with the PUFA constituents of PL or with free PUFAs which become incorporated into the PL by acyl transferases producing nonenzymatically derived oxPL. This oxygen transfer to PUFAs can further lead to DB rearrangement, cyclization and even truncation of such acyl-chains resulting in complex mixtures of oxPL (27).

TABLE 4C. Examples for shorthand notation of phosphatidylinositol phosphates

| Bond Type | Species Level | Phosphate Position Level | Molecular Species Level | <i>sn</i> -Position Level | Full Structure Level |
|-----------|---------------|--------------------------|-------------------------|---------------------------|--------------------------------------|
| Diacyl | PIP 36:1 | PIP(3') 36:1 | PIP(3') 16:0_18:1 | PIP(3') 16:0/18:1 | PIP(3') 16:0/18:1(9Z) |
| Diacyl | PIP2 38:4 | PIP2(4',5') 38:4 | PIP2(4',5') 18:0_20:4 | PIP2(4',5') 18:0/20:4 | PIP2(4',5') 18:0/20:4(4Z,8Z,11Z,14Z) |

TABLE 4D. Examples for shorthand notation of *N*-modified phospholipids

| Oxidative Modification | Species Level ^a | Molecular Species Level ^b | <i>sn</i> -Position Level ^c | Full Structure Level |
|------------------------|----------------------------|--------------------------------------|--|--|
| <i>N</i> -alkyl | PS-N(Alk) 40:3 | PS-N(6:0) 16:0_18:3 | PS-N(6:0) 16:0/18:3 | PS-N(6:0) 16:0/18:3(9Z,12Z,15Z) |
| <i>N</i> -acyl | PE-N(FA) 54:5 | PE-N(FA 18:1) 16:0_20:4 | PE-N(FA 18:1) 16:0/20:4 | PE-N(FA 18:1(9Z)) 16:0/20:4(4Z,8Z,11Z,14Z) |
| Hydroxynonenal adduct | PE-HNE 36:4 | PE-HNE 16:0_20:4 | PE-HNE 16:0/20:4 | PE-HNE 16:0/20:4(4Z,8Z,11Z,14Z) |



^a Annotation based on exact mass measurements using a high-resolution mass spectrometer, which allows differentiation of isobaric acyl and alkyl species.

^b Annotation requires MS/MS and detection of FA chain specific fragments.

^c *sn*-Positions determined by specific MS analysis like differential mobility spectrometry (34).

- Nonradical reactive oxygen species like singlet oxygen or ozone can also contribute to PL oxidation with generation of full-chain or fragmented oxPL.
- PL having a polar head group with a modified amino-function (PE and PS) form a subclass named oxPL-Nmod.

Shorthand notation for **OxPLs** in general are presented in Table 4E.

SPHINGOLIPIDS (SP)

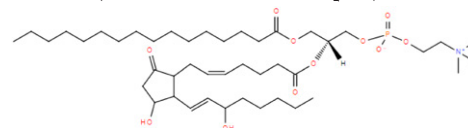
Apart from sphingosine containing 18 C-atoms with two hydroxyl groups and one DB, other sphingoid bases reveal prominent backbones as well, particularly in brain or nonmammalian specimens (28). Consequently, the abbreviation SPB is strongly recommended as shorthand notation for the general term “sphingoid bases,” Cer for ceramides, and SM for sphingomyelins (Table 5A). Table 5B, C, and D define, in addition, shorthand notation according to structural resolution of sphingolipids. The updated rules for shorthand notation are the following:

- In case the long-chain base is not known, the sum composition of sphingoid base and fatty acid is shown as number of C-atoms:DBE;O-atoms, e.g., SPB 34:1;O2.

- In ceramides the sphingoid backbone is annotated C-atoms:DBE;O-atoms separated by a slash from the number of C-atoms:DBE;O-atoms of the *N*-linked fatty acid, e.g., Cer 18:1;O2/16:0.
- DB geometry and positions of hydroxyl groups (or other functional groups) are annotated as described for fatty-acyl-chains in Tab. 2B, e.g., Cer 18:1(4E);1OH,3OH/16:0.
- When the number of hydroxyl groups cannot be determined, numbers of C-atoms and DBE are assigned under the assumption of the number of hydroxyl groups in the major sphingoid base for that organism (e.g., dihydroxy in mammals).
- For further characterization of *N*-linked fatty acids, the rules as described in the Annotation of lipid structures section apply. The position of a fatty acid esterified to an *N*-linked hydroxy-fatty acyl is shown in a separate pair of parentheses xO(FA C-atoms:DBE) with x denoting the position of hydroxyl group (Δ nomenclature) in the *N*-linked fatty acids, e.g., Cer 18:1;O2/26:0;18O(FA 16:0).
- Any modification linked to a sphingoid base-OH is written in front of the (sub)class abbreviation with the integrated position number in parenthesis at the end of abbreviation, e.g., FA 24:1-ACer (1) 18:1;3OH/16:0

Table 4E. Examples for shorthand notation of OxPLs

| Oxidative Modification | Species Level ^a | Molecular Species Level ^b | <i>sn</i> -Position Level ^c | Structure Defined Level | Full Structure Level |
|--------------------------|----------------------------|--------------------------------------|--|---------------------------------------|---|
| Hydroxylation | PC 36:4;O PC 34:1;O2 | PC 16:0_20:4;O PC 16:0_18:1;O2 | PC 16:0/20:4;O PC 16:0/18:1;O2 | PC 16:0/20:4;OH PC 16:0/18:1;(OH)2 | PC 16:0/20:4(5Z,8Z,10E,14Z);12OH PC 16:0/18:1(9Z);12OH,13OH |
| Epoxide | PC 34:2;O | PC 16:0_18:2;O | PC 16:0/18:2;O | PC 16:0/18:1;Ep | PC 16:0/18:1(9Z);12Ep |
| Hydroperoxide | PC 34:2;O2 | PC 16:0_18:2;O2 | PC 16:0/18:2;O2 | PC 16:0/18:2;OOH | PC 16:0/18:2(9Z,11E);13OOH |
| Peroxide | PC 34:2;O2 | PC 16:0_18:2;O2 | PC 16:0/18:2;O2 | PC 16:0/18:1;OO | PC 16:0/18:1(9Z);12OO |
| Aldehyde | PC 21:1;O | PC 16:0_5:1;O | PC 16:0/5:1;O | PC 16:0/5:0;oxo | PC 16:0/5:0;5oxo |
| Carboxylic acid | PC 25:1;O2 | PC 16:0_9:1;O2 | PC 16:0/9:1;O2 | PC 16:0/9:0;COOH | PC 16:0/9:0;8COOH |
| Hydroxy-aldehyde | PC 26:3;O2 | PC 18:1_8:2;O2 | PC 18:1/8:2;O2 | PC 18:1/8:1;OH;oxo | PC 18:1(9Z)/8:1(6E);5OH;8oxo |
| PC <i>sn</i> -2 position | PC 36:4;O3 | PC 16:0_20:4;O3 | PC 16:0/20:4;O3 | PC 16:0/20:2; [cy5;OH;oxo];OH | PC 16:0/20:2(5Z,13E);[8-12cy5;11OH;9oxo]; 15OH (common name 8-IsoPGE ₂ -PC) |



^a Annotation based on exact mass measurements using a high-resolution mass spectrometer, which allows differentiation of isobaric acyl and alkyl species.

^b Annotation requires MS/MS and detection of FA chain specific fragments.

^c *sn*-Positions determined by specific MS analysis like differential mobility spectrometry (34).

TABLE 5A. Class abbreviations in Category SP

| Common Name | Lipid Class, LIPID MAPS | Abbreviation |
|-------------------------------------|---|--------------|
| Sphingoid bases | Sphingoid bases [SP01] | SPB |
| Sphingoid base-phosphates | Sphingoid bases [SP0105] | SPBP |
| Ceramides | Ceramides [SP02] | Cer |
| Ceramide-phosphates | Ceramide phosphates [SP0205] | CerP |
| Acyl Ceramides | Acylceramides [SP0204] | ACer |
| Sphingomyelins | Phosphosphingolipids [SP03] | SM |
| Hexosylceramides | Neutral glycosphingolipids [SP05] | HexCer |
| Glucosylceramide | Neutral glycosphingolipids [SP05] | GlcCer |
| Galactosylceramide | Neutral glycosphingolipids [SP05] | GalCer |
| Dihexosylceramides | Neutral glycosphingolipids [SP05] | Hex2Cer |
| Lactosylceramide | Neutral glycosphingolipids [SP05] | LacCer |
| Sulfatides | Sulfoglycosphingolipids (sulfatides) [SP0602] | SHexCer |
| Inositolphosphorylceramides | Ceramide phosphoinositols [SP0303] | IPC (PI-Cer) |
| Ethanolaminophosphorylceramides | Ceramide phosphoethanolamines [SP0302] | EPC (PE-Cer) |
| Glycosylinositolphosphorylceramides | Ceramide phosphoinositols [SP0303] | GIPC |
| Mannosyl-inositolphosphoceramides | Ceramide phosphoinositols [SP0303] | MIPC |
| Mannosyl-diinositolphosphoceramide | Ceramide phosphoinositols [SP0303] | M(IP)2C |

for an acylceramide, Gal-Cer (1) 18:0;3OH/16:0 for a galactosylceramide.

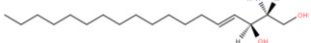
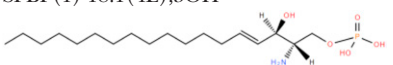
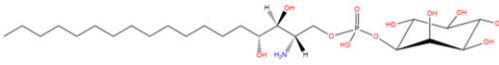
- Consequently, in shorthand notation from “Structure defined level” onwards only unmodified OH-groups of the sphingoid base are annotated.
- Shorthand notation for carbohydrate moieties is stated in Table 1C and examples are shown in Table 5D.
- For annotation of the sugar moiety in complex glycosphingolipids we refer to current practice in glycan science (<https://www.ncbi.nlm.nih.gov/glycans>) (15). When the sequence of sugars components is known, they are shown in this order separated by a hyphen. In case the sequence is unknown the components (followed by their number if more than one) are shown in alphabetic order in front of the respective lipid backbone. Annotation of the ceramide part follows the rules described above.
- Sphingoid base phosphates with unknown phosphate position are represented by SPBP, e.g., SPBP 18:1;(OH)2.

- Sphingoid base phosphates with known position of phosphate and of OH-positions is annotated by, e.g., SPBP (1) 18:1(4E);3OH.
- Ceramide phosphates with unknown phosphate position are represented by CerP, e.g., CerP 18:1;O2/16:0.
- Ceramide phosphates with known position of phosphate and of OH-positions are annotated by, e.g., CerP (1) 18:1(4E);3OH.
- Ceramide phosphates with 1,3 cyclic phosphate and known OH-positions are annotated by, e.g., CerP (1, 3) 18:1(4E).

STEROLS (ST)

We use the term sterol to embrace all molecules based on the cyclopentanoperhydrophenanthrene skeleton. **In the case of sterols, the ring system does not add to the number of DBE.** Endogenously biosynthesized mammalian sterols are derived from cholesterol or its

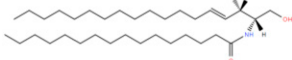
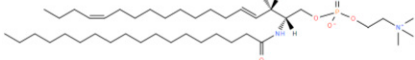
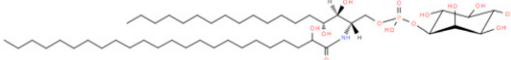
TABLE 5B. Examples for shorthand notation of sphingolipids with a free amino group

| Sphingoid Base | Species Level ^a | Structure Defined Level | Full Structure Level ^b |
|---------------------------------|----------------------------|-------------------------|--|
| Sphingosine | SPB 18:1;O2 | SPB 18:1;(OH)2 |  SPB 18:1(4E);1OH,3OH |
| 3-Keto-sphinganine | SPB 18:1;O2 | SPB 18:0;OH;oxo | SPB 18:0;1OH;3oxo |
| Sphinganine | SPB 18:0;O2 | SPB 18:0;(OH)2 | SPB 18:0;1OH,3OH |
| Sphingadiene | SPB 18:2;O2 | SPB 18:2;(OH)2 | SPB 18:2(4E,14Z);1OH,3OH |
| Phytosphingosine | SPB 18:0;O3 | SPB 18:0;(OH)3 | SPB 18:0;1OH,3OH,4OH |
| C20-sphingosine | SPB 20:1;O2 | SPB 20:1;(OH)2 | SPB 20:1(4E);1OH,3OH |
| Sphingosine-1-phosphate | SPBP 18:1;O2 | SPBP 18:1;OH | SPBP(1) 18:1(4E);3OH  |
| Sphinganine-1-phosphate | SPBP 18:0;O2 | SPBP 18:0;OH | SPBP(1) 18:0;3OH |
| 1-Deoxymethyl-sphinganine | SPB 17:0;O | SPB 17:0;OH | SPB 17:0;2OH |
| 1-Deoxy-sphinganine | SPB 18:0;O | SPB 18:0;OH | SPB 18:0;3OH |
| Lysoinositolphosphorylceramides | LIPC 18:0;O3 | LIPC 18:0;(OH)2 | LIPC(1) 18:0;3OH,4OH |
| Lysosphingomyelin | LSM 18:1;O2 | LSM 18:1;OH | LSM(1) 18:1(4E);3OH  |

^a Annotation based on exact mass measurements using a high-resolution mass spectrometer.

^b Positions of functional groups and DBs determined by independent techniques such as chromatographic resolution, ozonolysis (8) or photochemical derivatization (9).

TABLE 5C. Examples for shorthand notation of sphingolipids containing an amide bound fatty acid

| Phyla | Species Level ^a | Molecular Species Level ^b | Full Structure Level ^c |
|-----------|----------------------------|--|--|
| Mammalian | Cer 34:1;O2 | Cer 18:1;O2/16:0 | Cer 18:1(4E);1OH,3OH/16:0  |
| Mammalian | Cer 34:0;O2 | Cer 18:0;O2/16:0 | Cer 18:0;1OH,3OH/16:0 |
| Mammalian | ACer 58:1;O2 | FA 24:1-ACer 18:1;O2/16:0 | FA 24:1-ACer(1) 18:1(4E);3OH/16:0 |
| Mammalian | CerP 34:1;O2 | CerP 18:1;O2/16:0 | CerP(1) 18:1(4E);3OH/16:0 |
| Mammalian | SM 36:2;O2 ^d | SM 18:2;O2/18:0 | SM(1) 18:2(4E,14Z);3OH/18:0  |
| Mammalian | SM 44:2;O2 ^d | SM 20:1;O2/24:1 | SM(1) 20:1(4E);3OH/24:1(15Z) |
| Mammalian | Cer 62:3;O4 | Cer 18:1;O2/26:0;O(FA 18:1) ^e | Cer 18:1(4E);1OH,3OH/26:0;26O(FA 18:1(9Z)) |
| Plant | IPC 42:1;O4 | Cer 18:1;O2/44:2;O2 ^f | IPC(1) 18:1(8E);3OH,4OH/24:0;2OH  |
| Yeast | Cer 44:0;O5 | Cer 18:0;3O/26:0;O2 | Cer 18:0;1OH,3OH,4OH/26:0;2OH,3OH |

^a Annotation based on exact mass measurements using a high-resolution mass spectrometer.

^b Annotation requires MS/MS enabling detection of sphingoid base and/or *N*-linked FA.

^c Positions of functional groups and DBs determined by independent techniques such as chromatographic resolution, ozonolysis (8) or photochemical derivatization (9).

^d Annotation using low resolution MS QQQ and a PIS *m/z* 184 requires the assumption of a sphingoid base with two hydroxyl groups.

^e Annotation with structural characterization of O-acyl in *N*-linked acyl chain.

^f Annotation without structural differentiation of *N*-linked acyl chain.

precursors, yet plant and yeast sterols can also be a source via the food chain. The stereochemistry of the cholesterol molecule is maintained to a large extent by mammalian sterols, which all contain at least one hydroxyl or oxo group attached to carbon 3. High resolution MS with accurate mass may identify other functional groups, as will MS/MS or MSⁿ scans. Stereochemistry can often be defined by comparing the chromatographic retention time to authentic standards and, in some cases, by MS/MS or MSⁿ. The class abbreviations within category ST are shown in **Table 6A**.

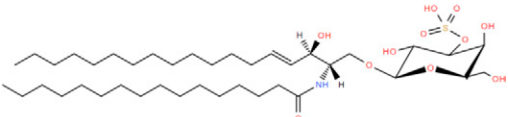
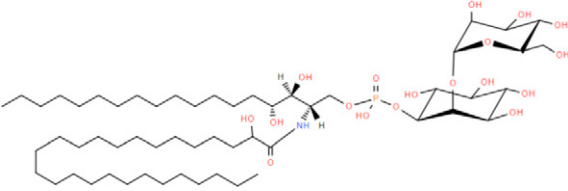
The following rules for shorthand nomenclature have been adopted in the examples given in Table 6B.

- In shorthand notation the category abbreviation ST is used as class abbreviation. In some cases, other abbreviations e.g., FC, CE, BA, SE, SG and ASG can be used. In all cases, class abbreviation is followed by number of carbon atoms:number of DB, and separated by semicolon is the number of oxygens, e.g., ST 27:1;O for cholesterol and lathosterol (also zymostenol), or ST 24:1;O5 for an oxidized sterol *and* for cholic acid *and* ursocholic acid. The latter is an important point: Some bile acids have an identical mass and molecular formula to oxidized sterols lacking a carboxylic acid group. This must be considered, when class abbreviation "BA" is used.
- Shorthand notation of further functional groups are written, separated by a semicolon, after the number of oxygens, e.g., BA 24:1;O5;T for taurocholic acid (= common name, abbreviation TCA).
- Following the number of double bonds, proven position and stereochemistry is shown. R and S configurations are

preferred for side-chain stereochemistry and are shown in square brackets. α (below ring/plane), written as a, and β (above ring/plane), written as b, are preferred for ring stereochemistry, e.g. 3aOH and 17bOH. Stereochemistry at C-5 introduced by reduction of the Δ^5 bond is indicated by 5aH or 5bH. Replacing the number of oxygens, proven positions and stereochemistry of oxygen containing functional groups are shown. If such stereochemistry is known the common name of the compound can be used.

- The side-chain at carbon-17 of the cyclopentanoperhydrophenanthrene skeleton always has b-stereochemistry (17b) and consequently is not presented in the shorthand annotation.
- For structures fully proven or based on assumption by biological intelligence, such as e.g., cholesterol, cholesterol esters, steryl esters, bile acids, sterylglycosides, and acylsterylglycosides abbreviations FC, CE, SE, BA, SG and ASG, respectively, can be used as shown in Table 6A. CE is followed by number of C-atoms:number of DBE of the fatty acid esterified to the hydroxyl group at position 3, e.g., CE 18:2 (Table 6B). Shorthand notation SE is used as above followed by slash (for monohydroxysterols) or underscore (for polyhydroxysterols) number of C-atoms:number DBE of the fatty acid esterified to the hydroxyl group (Table 6B).
- MS/MS scans reveal the presence of conjugates: Taurine (T) and glycine (G) each are conjugated through an amide bond to the carboxylic acid group of bile acids, respective amide bonds with conjugates are designated in shorthand notation "COT" and "COG" (Table 6B); sulfuric acid (S) is conjugated to a hydroxyl group through an ester bond; glucuronic acid (GlcA), *N*-acetylglucosamine

TABLE 5D. Examples for shorthand notation of glycosphingolipids containing an amide bound fatty acid

| Phyla | Species Level ^a | Molecular Species Level ^b | Full Structure Level ^c |
|-----------|----------------------------|---|---|
| Mammalian | Hex-Cer 34:1;O2 | Hex-Cer 18:1;O2/16:0 Glc-Cer 18:1;O2/16:0 ^d | Glc-Cer(1) 18:1(4E);3OH/16:0 (see also Fig. 1) |
| Mammalian | Hex-Cer 34:0;O2 | Hex-Cer 18:0;O2/16:0 Gal-Cer 18:0;O2/16:0 ^d | Gal-Cer(1) 18:0;3OH/16:0 |
| Mammalian | Hex2Cer 34:1;O2 | Hex2Cer 18:1;O2/16:0 | Lac-Cer(1) 18:1(4E);3OH/16:0 ^e Gal-Glc-Cer(1) 18:1(4E);3OH/16:0 |
| Mammalian | Hex3Cer 42:1;O2 | Hex3Cer 18:1;O2/24:0 | Gal-Gal-Glc-Cer(1) 18:1(4E);3OH/24:0 (= Gb3) |
| Mammalian | NeuAcHex2Cer 42:1;O2 | NeuAcHex2Cer 18:1;O2/24:0 | NeuAc-Gal-Glc-Cer(1) 18:1(4E);3OH/24:0 (= GM3) |
| Mammalian | NeuAc2Hex2Cer 42:1;O2 | NeuAc2Hex2Cer 18:1;O2/24:0 | NeuAc-NeuAc-Gal-Glc-Cer(1) 18:1(4E);3OH/24:0 (= GD3) |
| Mammalian | SHex-Cer 34:1;O2 | SHex-Cer 18:1;O2/16:0 | S(3')Hex-Cer(1) 18:1(4E);3OH/16:0 S(3')Gal-Cer(1) 18:1(4E);3OH/16:0 ^e |
| | | |  |
| Mammalian | SHexHexNAcHex3Cer 34:1;O2 | SHexHexNAcHex3Cer 18:1;O2/16:0 | S(3')Hex-HexNAc-Hex-Hex-Hex-Cer(1) 18:1(4E);3OH/16:0 S(3')Gal-GalNAc-Gal-Gal-Glc-Cer(1) 18:1(4E);3OH/16:0 ^e (globopentaosylceramide sulfate) |
| Plant | HexA-IPC 42:1;O4 | HexA-IPC 18:1;O3/24:0;O | GlcA-IPC(1) 18:1(8E);3OH,4OH/24:0;2OH |
| Plant | HexHexA-IPC 42:1;O4 | Hex-HexA-IPC 18:1;O3/24:0;O | Glc-GlcA-IPC(1) 18:1(8E);3OH,4OH/24:0;2OH |
| Plant | HexAHexNAc-IPC 42:1;O4 | HexNAc-HexA-IPC 18:1;O3/24:0;O | GlcNAc-GlcA-IPC(1) 18:1(8E);3OH,4OH/24:0;2OH |
| Plant | HexHexAHexNAc-IPC 42:1;O4 | Hex-HexNAc-HexA-IPC 18:1;O3/24:0;O | Glc-GlcNAc-GlcA-IPC(1) 18:1(8E);3OH,4OH/24:0;2OH |
| | | |  |
| Yeast | MIPC 44:0;O4 | MIPC 18:0;O3/26:0;O | MIPC(1) 18:0;3OH,4OH/26:0;2OH |
| Yeast | M(IP)2C 46:0;O4 | M(IP)2C 20:0;O3/26:0;O | M(IP)2C(1) 20:0;3OH,4OH/26:0;2OH |

^a Annotation based on exact mass measurements using a high-resolution mass spectrometer.

^b Annotation requires MS/MS enabling detection of sphingoid base and/or *N*-linked FA.

^c Positions of functional groups and DBs determined by independent techniques such as chromatographic resolution, ozonolysis (8) or photochemical derivatization (9).

^d Separation of isomeric hexosylceramide by HILIC (36).

^e Annotation requires separation of stereoisomers at glycosidic linkage (α/β).

(GlcNAc), and hexose (Hex) sugars are assumed to be linked to a hydroxyl group through an acetal linkage (Table 6B).

- In the case full stereochemistry is known the common names as presented in Table 6B can be used.

DISCUSSION AND CONCLUSIONS

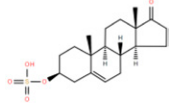
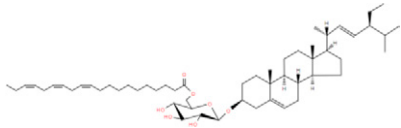
This publication updates both the classification and nomenclature (2, 3) and shorthand notation (4), and targets two goals. First, to emphasize and enable correct reporting of mass spectrometric data according to the

resolving power of MS instrument platforms operating in high-resolution (and often high-throughput) mode. Second, to provide a comprehensible shorthand notation for the lipids commonly analyzed. Such common nomenclature is essential for standardized reporting of lipid species data and construction of data resources. Moreover, standardized data facilitate automated datamining and import into databases by script-based algorithms with only minimal data curation. Related data repositories require a hierarchical concept mirroring the structural resolution provided by mass spectrometric analysis reflected in the presented shorthand notation. To this end, the LMSD database, respective MS search tool, and, in

TABLE 6A. Class abbreviations in Category ST

| Common Name | Lipid Class, LIPID MAPS | Abbreviation |
|--------------------------------|-----------------------------------|--------------|
| Sterols | Sterols [ST01] | ST |
| Sterol esters | Sterol esters [ST0102] | SE |
| Bile acids | Bile acids and derivatives [ST04] | BA |
| Free cholesterol = cholesterol | | FC |
| Cholesteryl ester | Cholesteryl esters [ST0102] | CE |
| Sterylglycosides | Sterylglycosides | SG |
| Acylsterylglycosides | Monoradylglycoesters | ASG |

TABLE 6B. Examples of shorthand notation for sterols

| Lipid Class | Species Level | Full Structure Level | Complete Structure Level (= Common Name) |
|-------------|-----------------------|---|--|
| ST (FC) | ST 27:1;O | ST 27:1 (5Z);3bOH = FC | Cholesterol |
| ST | ST 27:1;O | ST 27:1 (7);5aH;3bOH | Lathosterol |
| ST | ST 28:3;O | ST 28:3 (5Z,7Z,22E);24Me[R];3bOH | Ergosterol |
| ST | ST 27:2;O3 | ST 27:1 (5Z);3bOH;26COOH[25R] | 3 β -Hydroxycholest-5-en-(25R)26-oic acid |
| SE | SE 27:1/16:0 | CE 16:0 | Cholesteryl palmitate |
| SE | SE 27:1/18:2 | CE 18:2 (9Z,12Z) | Cholesteryl linoleate |
| SE | SE 27:2/18:1 | SE 27:2 (8E,24);5aH/18:1 (9Z) | Zymosteryl oleate |
| ST | ST 21:3;O2 | ST 21:1 (4Z);3oxo,20oxo | Progesterone |
| ST | ST 19:2;O2 | ST 19:1 (4Z);17bOH;3oxo | Testosterone |
| ST | ST 19:2;O2 | ST 19:1 (5Z);3bOH;17oxo | Dehydroepiandrosterone |
| ST | ST 18:3;O2 | ST 18:3 (1,3,5);3OH,17bOH | 17 β -Estradiol |
| ST | ST 19:2;O2;S | ST 19:1 (5Z);3bS;17oxo | Dehydroepiandrosterone sulfate |
| | | |  |
| BA | ST 24:1;O5 | BA 24:0;5bH;3aOH,7aOH,12aOH;24COOH | Cholic acid (CA) |
| BA | ST 24:1;O3 | BA 24:0;5bH;3aOH;24COOH | Lithocholic acid (LCA) |
| BA | BA 24:1;O5;T | BA 24:0;5bH;3aOH,7aOH,12aOH;24COT | Taurocholic acid (TCA) |
| BA | BA 24:1;O4;G | BA 24:0;5bH;3aOH,7aOH;24COG | Glycochenodeoxycholic acid (GCDCA) |
| BA | ST 24:1;O4;HexNAc | BA 24:0;5bH;3aOH,7bOGlcNAc;24COOH | Ursodeoxycholic acid 7 β -N-acetylglucosaminide (UDCA-GlcNAc) |
| SG | SG 27:1;O;Hex | SG 27:1 (5Z);3bOGlc | Cholesteryl glucoside |
| ASG | ASG 29:2;O;Glc;FA20:3 | ASG 29:2 (5Z,22E);24Et[S];3bOGlc;6O (FA 20:3) | 20:3 (11Z,14Z,17Z)-Glc-stigmasterol |
| | | |  |

particular, shorthand notations for all relevant lipids are now available on the LMSD detail view pages at “Species level” and “Molecular species level”, the latter embracing “Phosphate-”, “DB-”, and “*sn*-position level”. In a few instances, however, easy use of this shorthand notation by lipidomics experts has priority over its stringent use in a bioinformatics format.

A standardized annotation for lipid species, as a common language, is a key component to promote and further advance this emerging omics discipline (29). Therefore, the Lipidomics Standards Initiative (LSI; <https://lipidomics-standards-initiative.org/>) has been recently introduced (13), pursuing development of guidelines and channeling community-wide efforts in close collaborations with LIPID MAPS (<https://www.lipidmaps.org/>) as has been emphasized recently (30). In addition, alignment with other initiatives, as for example, adaptation of mzTab-M, a data format developed for metabolomics (31), to the presented nomenclature is possible.

In summary, the shorthand nomenclature presented here is viewed as a standard in lipidomics that can be updated periodically.

Data availability















All data are contained within this article. 

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Conflict of interest

The authors declare that they have no conflicts of interest with the contents of this article.

Abbreviations

DB, double bond; DBE, double bond equivalent; LMSD, LIPID MAPS Structure Database; OxPL, oxygenated phospholipid.

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