Genome-wide association studies of metabolites in Finnish men identify disease-relevant loci

Xianyong Yin[1], Lap Sum Chan[1], Debraj Bose[1], Anne U. Jackson[1], Peter VandeHaar[1], Adam E. Locke[2], Christian Fuchsberger[1,3], Heather M. Stringham[1], Ryan Welch[1], Ketian Yu[1], Lilian Fernandes Silva[4], Susan K. Service[5], Daiwei Zhang[1,6], Emily C. Hector[7], Erica Young[2,8], Liron Ganel[2], Indraniel Das[2], Haley Abel[9], Michael R. Erdos[10], Lori L. Bonnycastle[10], Johanna Kuusisto[4,11], Nathan O. Stitziel[2,8,12], Ira M. Hall[13], Gregory R. Wagner[14], FinnGen*, Jian Kang[1], Jean Morrison[1], Charles F. Burant[15], Francis S. Collins[10], Samuli Ripatti[16,17,18], Aarno Palotie[16,17,19], Nelson B. Freimer[5], Karen L. Mohlke[20], Laura J. Scott[1], Xiaoquan Wen[1], Eric B. Fauman[21,22], Markku Laakso[4,22], Michael Boehnke[1,22]

Supplementary Material

Supplementary Note 1

Supplementary Table 1: Ten biochemical classes of the assayed metabolites

Class	Abbreviation
Amino acid	AA
Carbohydrate	CA
Cofactors and vitamins	CV
Energy	EN
Lipid	LI
Nucleotide	NU
Partially characterized	PC
Peptide	PE
Xenobiotics	XE
Unnamed	UN

Class: biochemical class of the metabolites.

Supplementary Table 2: Characteristics of METSIM participants and those with Metabolon metabolomics data

Characteristic	All	Metabolon	Analysis
Sample size	10,197	6,490	6,136
Age at baseline (years, mean ± SD)	57.8 ± 7.1	58.0 ± 7.0	58.1 ± 7.0
BMI (kg/m^2, mean ± SD)	27.3 ± 4.2	26.8 ± 3.7	26.7 ± 3.6
Waist circumstance (cm, mean ± SD)	98.8 ± 11.5	97.4 ± 10.5	97.1 ± 10.1
Fasting glucose (mmol/l, mean ± SD)	6.0 ± 1.1	5.8 ± 0.8	5.7 ± 0.5
Diabetics at baseline %	14.1	4.1	0.0
Current smoker %	18.1	16.1	16.0
Blood pressure medication use %	39.2	35.5	34.5
Lipid lowering medication use %	28.2	26.2	25.4

SD: standard deviation. Analysis: the analysis set after quality control.

Supplementary Table 3a: Numbers of genetic variants by variant type in the METSIM imputation reference panel

Variant type	Rare (MAF<1%)	Common (MAF≥1%)	All
Single nucleotide variant	14,765,788	8,528,549	23,294,337
Insertion/deletion	1,752,855	1,098,993	2,851,848
Total	16,518,643	9,627,542	26,146,185

MAF: minor allele frequency.

Supplementary Table 3b: Numbers of genetic variants by variant annotation in the METSIM imputation reference panel

Variant annotation	Rare (MAF<1%)	Common (MAF≥1%)	All
Intron	8,998,202	5,172,297	14,170,499
Intergenic	5,101,805	3,117,352	8,219,157
Downstream/upstream	1,902,347	1,109,324	3,011,671
3' UTR	165,893	82,936	248,829
Non-coding transcript exon	123,505	72,800	196,305
Missense	108,023	25,100	133,123
Synonymous	56,499	25,162	81,661
5' UTR	32,858	13,216	46,074
Splice region	16,632	7,384	24,016
Frameshift	3,642	340	3,982
Stop gained	3,143	225	3,368
Inframe deletion	1,951	443	2,394
Splice donor	1,534	356	1,890
Splice acceptor	1,230	243	1,473
Inframe insertion	901	260	1,161
Start lost	276	45	321
Stop lost	135	39	174
Others	67	20	87
Total	16,518,643	9,627,542	26,146,185

MAF: minor allele frequency. Others includes incomplete_terminal_codon_variant, transcript_ablation, protein_altering_variant, mature_miRNA_variant, and coding_sequence_variant annotations in Variant Effect Predictor (VEP).

Supplementary Table 4a: Numbers of genetic variants with genotype imputation r2≥0.3 by variant type in the 6,490 METSIM participants with Metabolon metabolomics data

Variant type	Rare (MAF<1%)	Common (MAF≥1%)	All
Single nucleotide variant	10,656,966	8,526,031	19,182,997
Insertion/deletion	1,306,701	1,098,016	2,404,717
Total	11,963,667	9,624,047	21,587,714

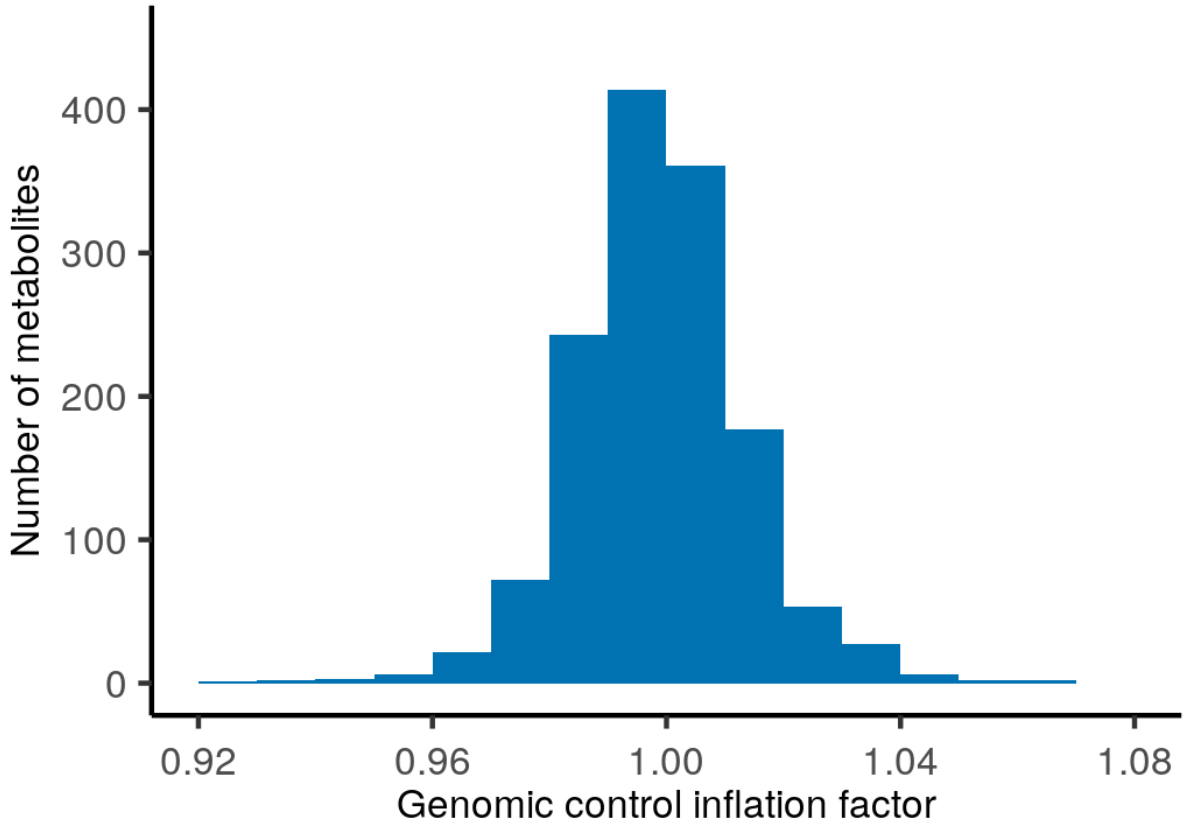
MAF: minor allele frequency.

Supplementary Table 4b: Numbers of genetic variants with genotype imputation r2≥0.3 by variant annotation in the 6,490 METSIM participants with Metabolon metabolomics data

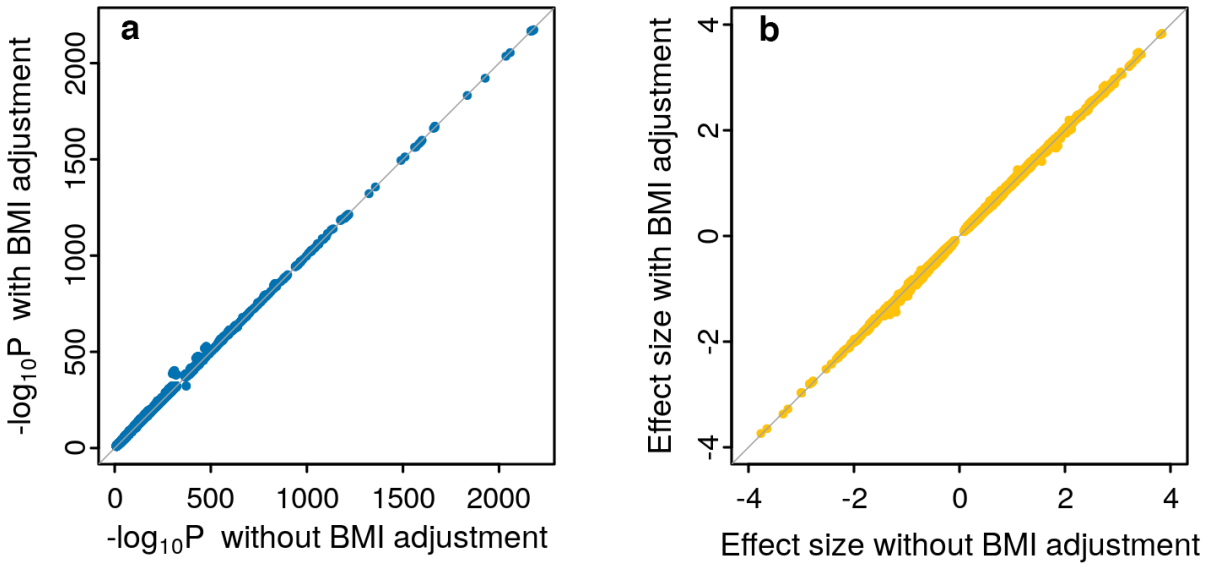
Variant annotation	Rare (MAF<1%)	Common (MAF≥1%)	All
Intron	7,010,536	5,575,203	12,585,739
Intergenic	3,099,351	2,619,219	5,718,570
Downstream/upstream	1,456,125	1,174,576	2,630,701
Non-coding transcript exon	116,862	95,642	212,504
3' UTR	121,829	84,387	206,216
Missense	73,393	25,394	98,787
Synonymous	40,008	25,316	65,324
5' UTR	24,437	14,079	38,516
Splice region	12,516	8,096	20,612
Frameshift	2,379	364	2,743
Stop gained	1,924	239	2,163
Inframe deletion	1,332	437	1,769
Splice donor	1,114	419	1,533
Splice acceptor	886	311	1,197
Inframe insertion	648	262	910
Start lost	201	44	245
Stop lost	76	40	116
Others	50	19	69
Total	11,963,667	9,624,047	21,587,714

MAF: minor allele frequency. Others includes incomplete_terminal_codon_variant, transcript_ablation, protein_altering_variant, mature_miRNA_variant, and coding_sequence_variant annotations in Variant Effect Predictor (VEP).

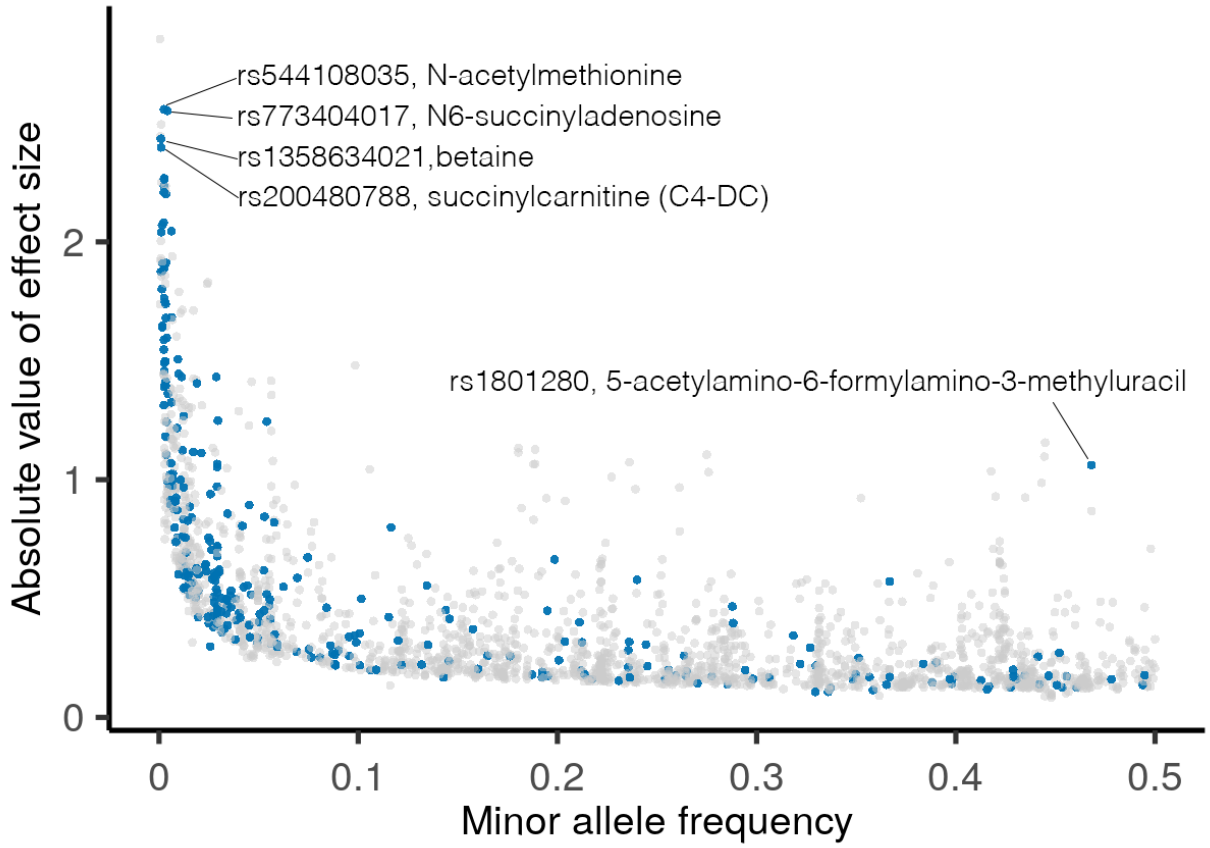
Supplementary Figure 1: Distribution of genomic control inflation factors for the 1,391 metabolite GWAS (median=1.00).



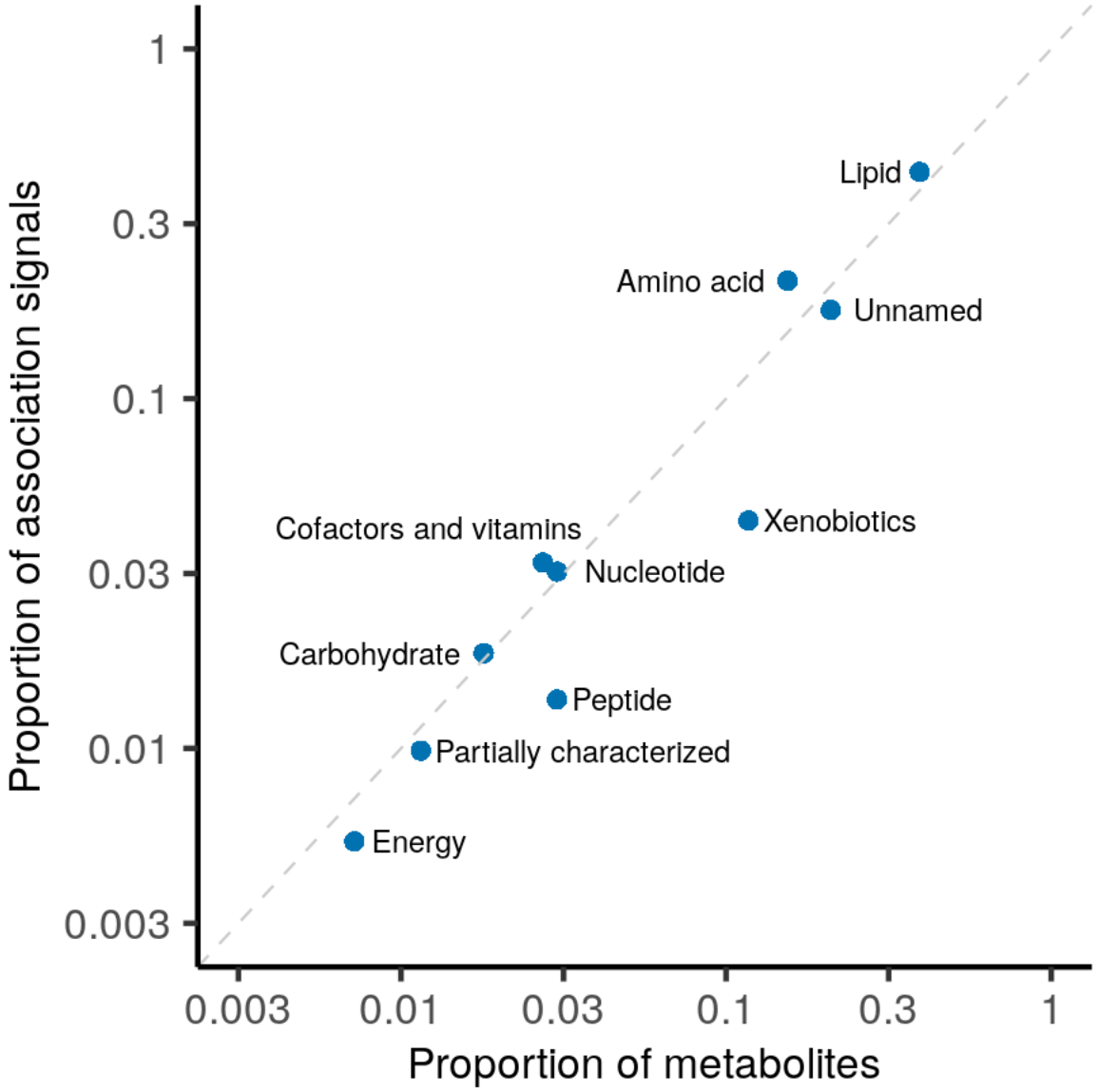
Supplementary Figure 2: Comparison of significant single-variant association results ($P<7.2\times10^{-11}$) with or without adjustment for BMI: **a** $-\log_{10}P$ and **b** effect size estimate. For each comparison, the Pearson correlation coefficient r=0.999. Each dot represents a genetic variant-metabolite pair.



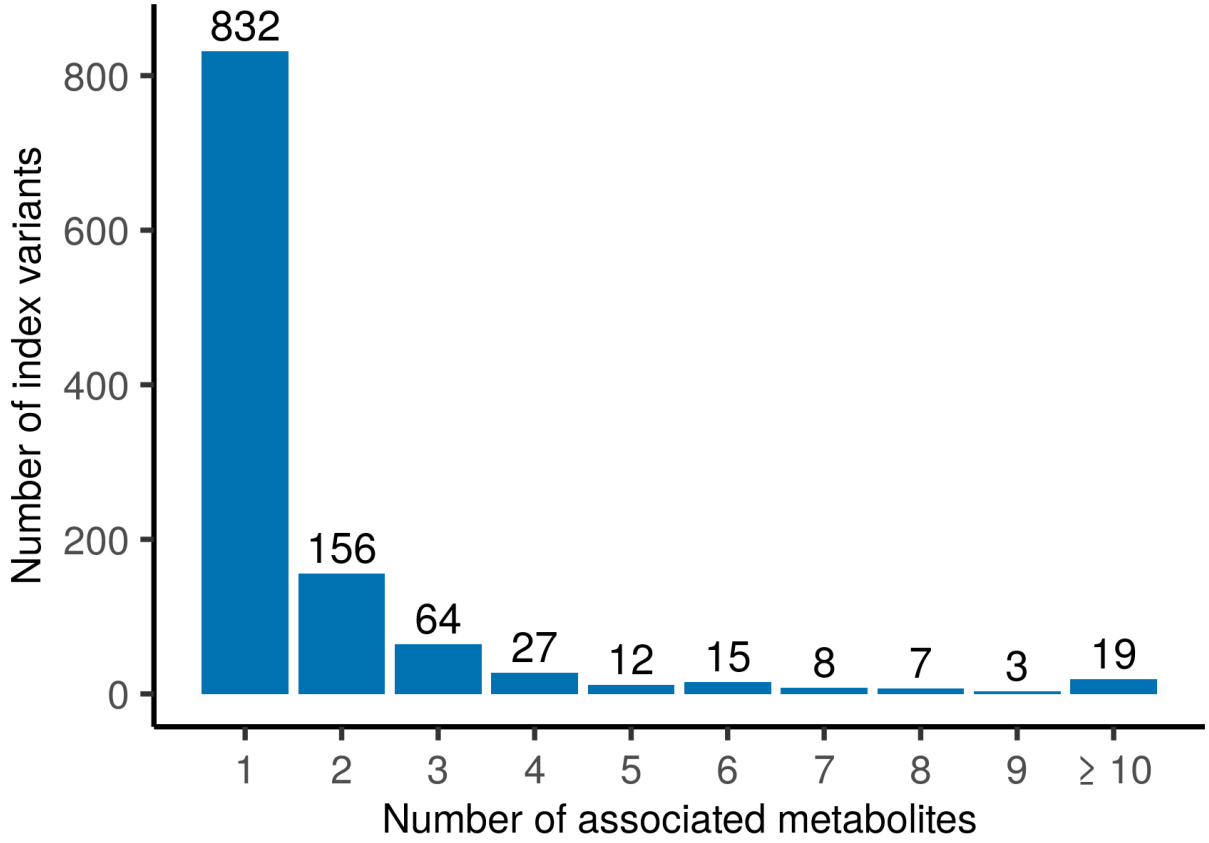
Supplementary Figure 3: Absolute value of the effect size estimate is inversely correlated with minor allele frequency (MAF) for the 2,030 conditional association signals (1,143 index variants; $P<7.2\times10^{-11}$). Each dot represents an association signal. Novel signals are colored in blue. Effect size was estimated for inverse normalized metabolite level residuals after regression on covariates. Four novel association signals at rare variants and one at a common variant are labeled.



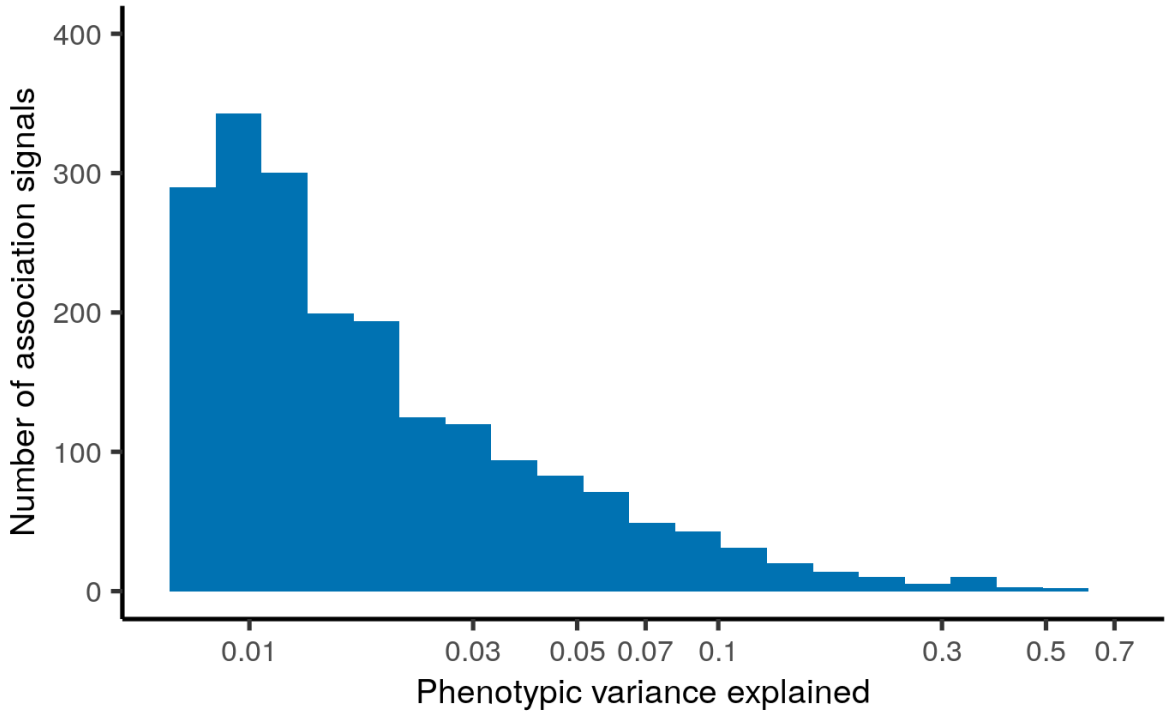
Supplementary Figure 4: Relationship between the number of metabolites and the number of significant conditional association signals at $P<7.2x10^{-11}$ for the ten metabolite biochemical classes. The proportion of metabolites and association signals are plotted on the log scale.



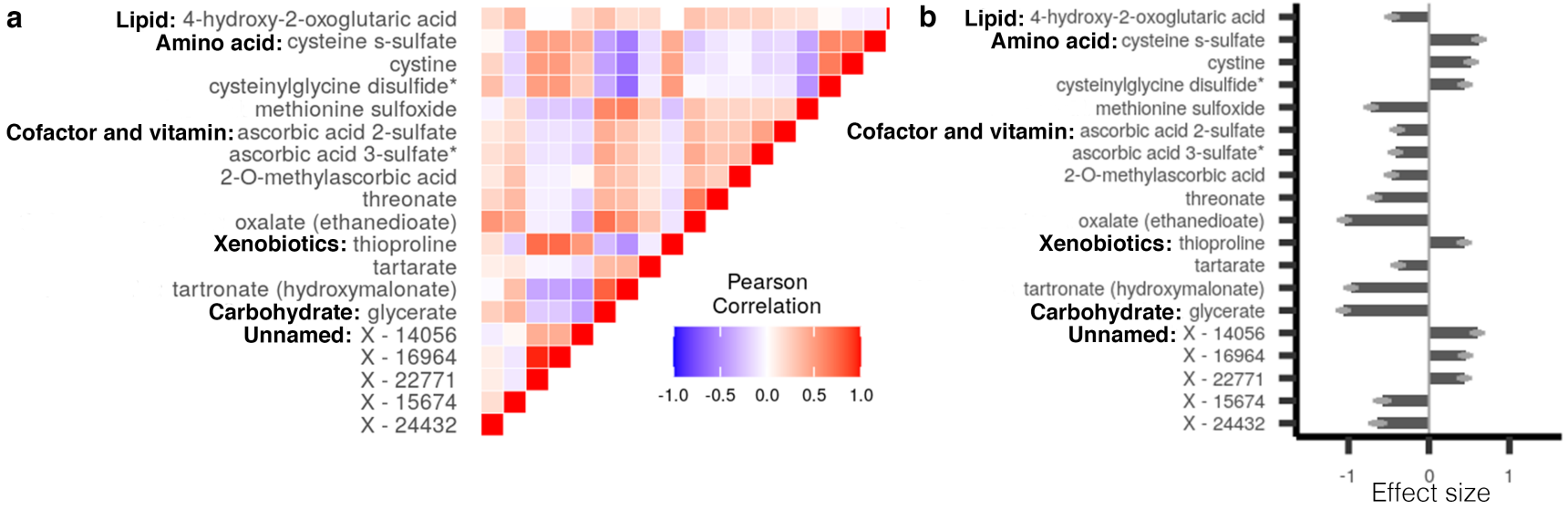
Supplementary Figure 5: Number of metabolites associated with each of the 1,143 index variants.



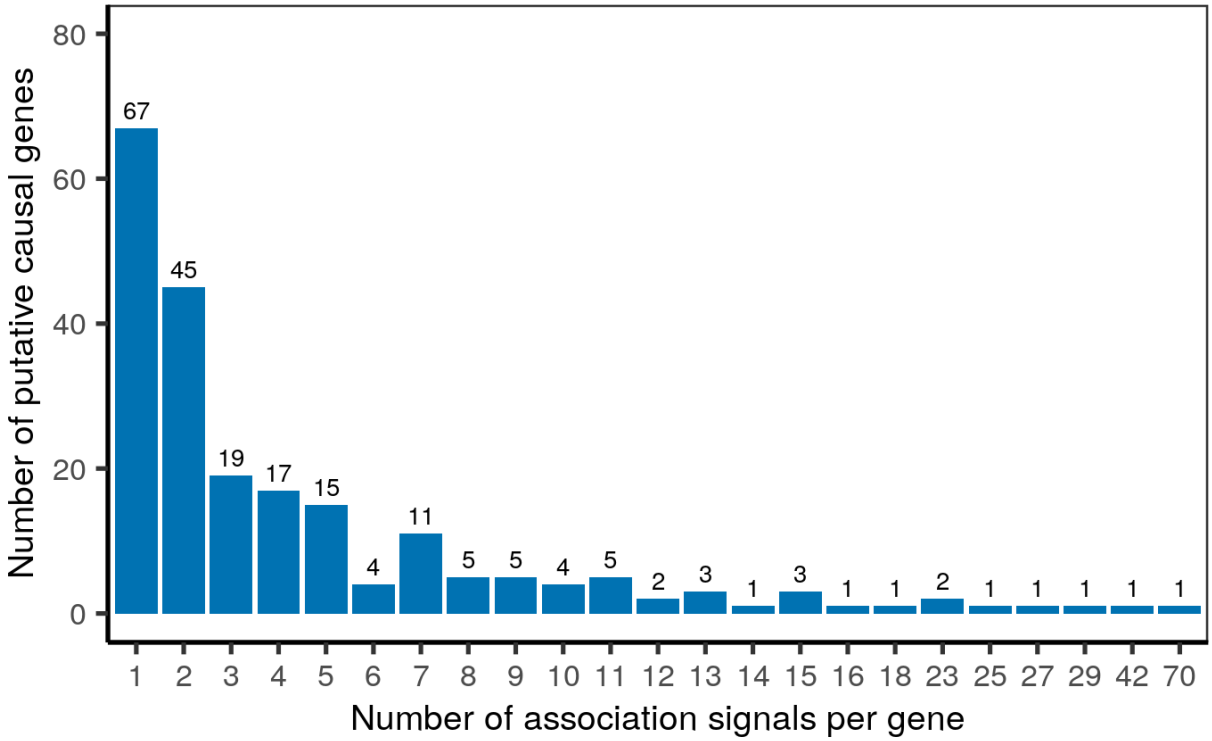
Supplementary Figure 6: Distribution of metabolite phenotypic variance explained by the index variant for each of the 2,030 significant association signals. The distribution is plotted on the log scale.



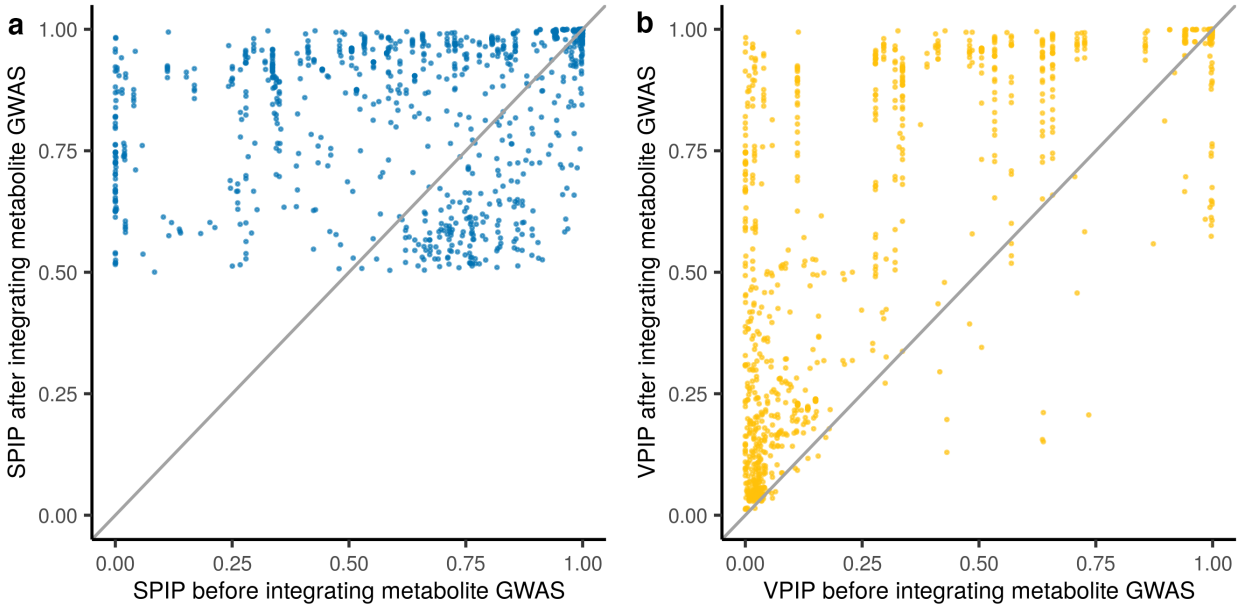
Supplementary Figure 7: Significant genetic associations (P<7.2x10^{-11}) between *SLC23A3* missense variant p.Asn336Lys (rs192756070) and 19 metabolites. **a** Phenotypic correlations between the 19 metabolites; and **b** Effect size estimates and standard errors for the 19 metabolite association signals sorted by biochemical class. Within each class, metabolites are sorted by their association effect sizes.



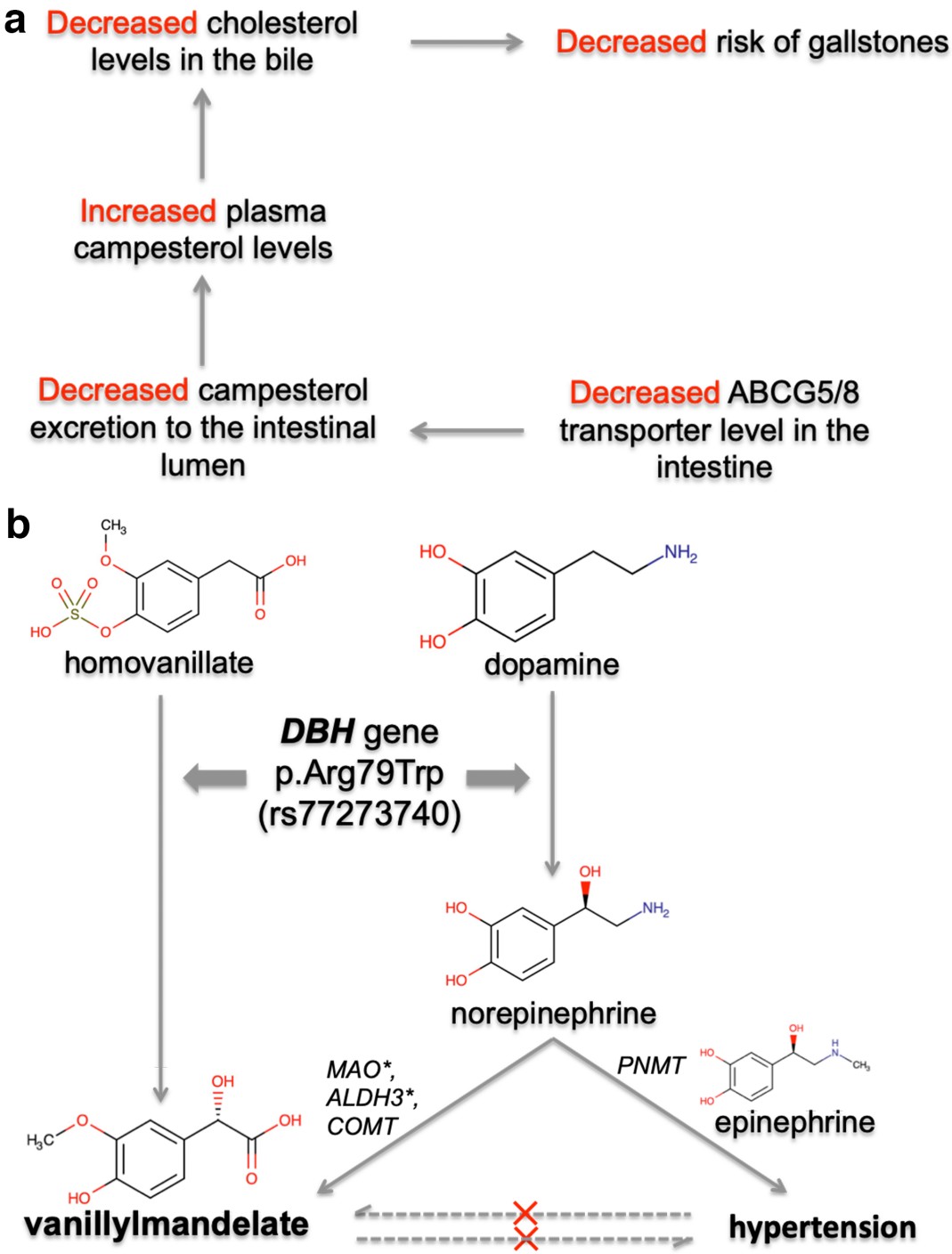
Supplementary Figure 8: Number of conditional association signals associated with each of the 215 putative causal genes.



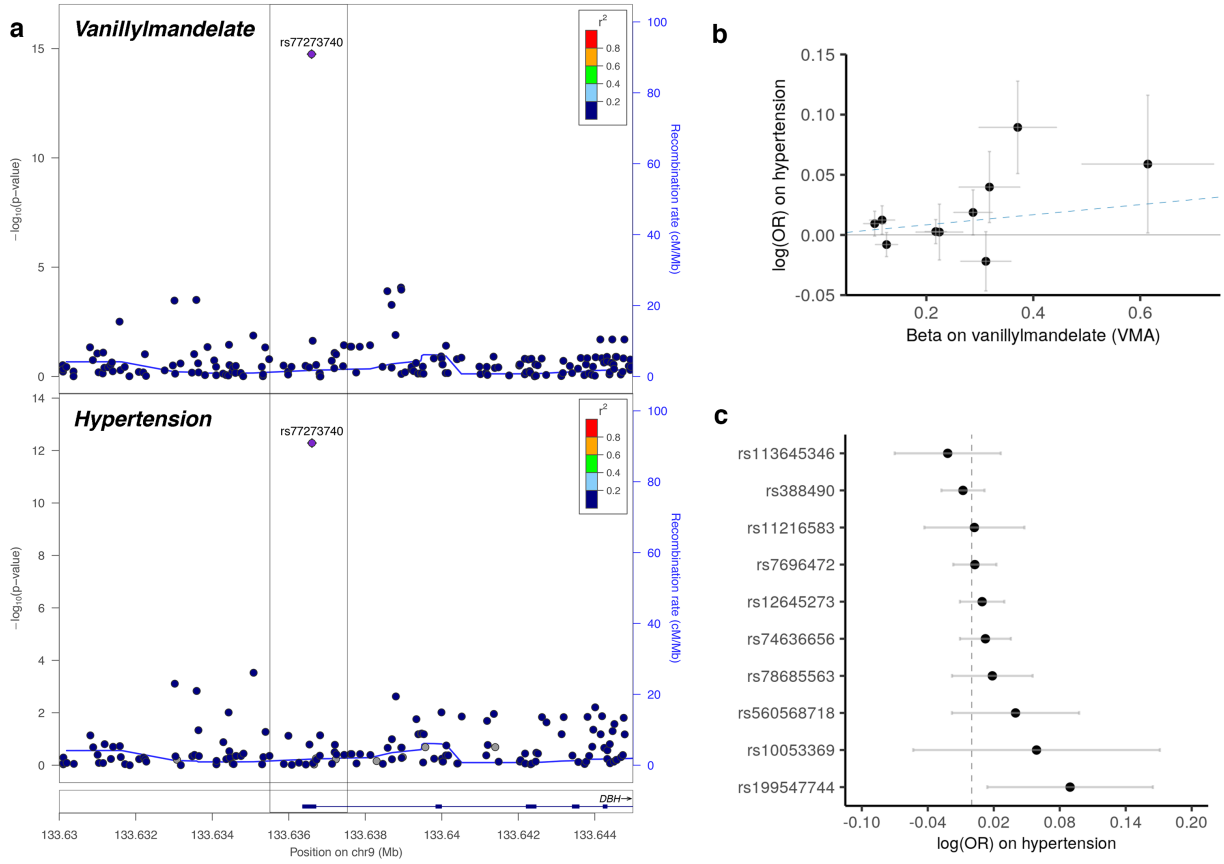
Supplementary Figure 9: Integrating metabolite GWAS into FinnGen disease genetic association results through colocalization analysis increases the posterior probabilities of **a** 64% of the disease association signals (SPIP); and **b** 90% of the putative causal variants (VPIP). SPIP is the estimated probability that there is an association signal in the region. Here, VPIP is the largest posterior probability that one of the genetic variants is causal. Each point denotes in **a** an association signal and in **b** a genetic variant.



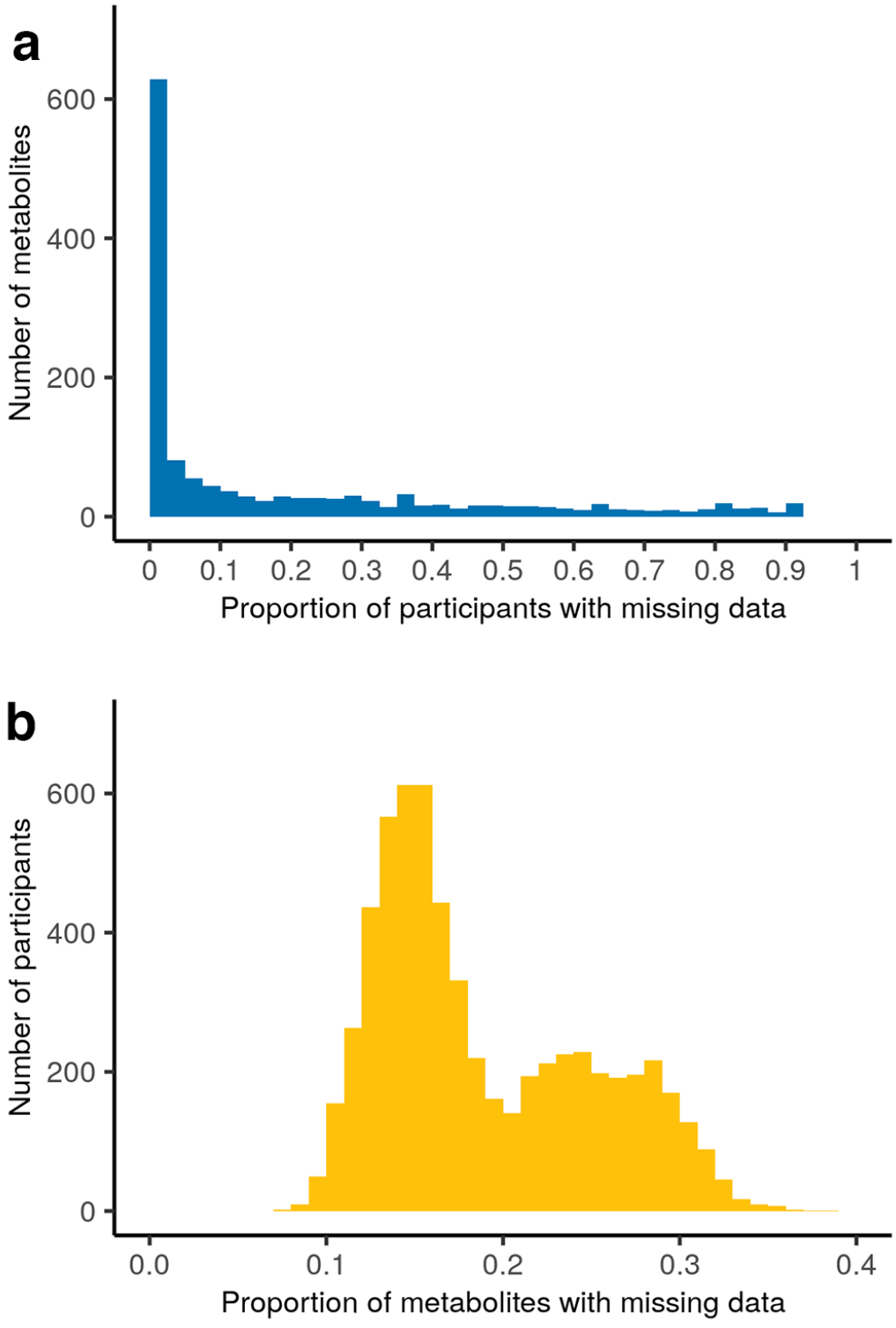
Supplementary Figure 10: Pathways from metabolite to diseases mediated by gene. **a** Potential causal pathway from plasma campesterol to the risk of gallstones at the *ABCG5/ABCG8* region; and **b** the potential distinct effects of the *DBH* gene on plasma vanillylmandelate (VMA) and the risk of hypertension.



Supplementary Figure 11: Dopamine beta hydroxylase (*DBH*) influence on vanillylmandelate and hypertension: distinct pathways. **a** Stacked regional association plots for vanillylmandelate and hypertension in the *DBH* region of chromosome 9. Genetic variants are colored by their linkage disequilibrium (LD) in METSIM to the index variant rs77273740; **b** Comparison of effect sizes of ten instrumental variables without significant heterogeneity (*P*>0.05) in the genome used in the Mendelian randomization analysis between vanillylmandelate and hypertension. The slope of the blue dashed line depicts the estimated effect of vanillylmandelate on hypertension in Mendelian randomization analysis; and **c** Effects on hypertension of ten instrumental variables used in Mendelian randomization analysis. OR: odds ratio.



Supplementary Figure 12: Proportion of **a** METSIM participants with missing data for each of the 1,391 metabolites; and **b** metabolites with missing data among the 6,136 METSIM participants in the analysis dataset.



Supplementary Note 1

FinnGen Contributors

Steering Committee

Aarno Palotie Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mark Daly Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Pharmaceutical companies

Bridget Riley-Gills Abbvie, Chicago, IL, United States
Howard Jacob Abbvie, Chicago, IL, United States
Dirk Paul Astra Zeneca, Cambridge, United Kingdom
Heiko Runz Biogen, Cambridge, MA, United States
Sally John Biogen, Cambridge, MA, United States
Robert Plenge Celgene, Summit, NJ, United States/Bristol Myers Squibb, New York, NY, United States
Joseph Maranville Celgene, Summit, NJ, United States/Bristol Myers Squibb, New York, NY, United States
Mark McCarthy Genentech, San Francisco, CA, United States
Julie Hunkapiller Genentech, San Francisco, CA, United States
Meg Ehm GlaxoSmithKline, Brentford, United Kingdom
Kirsi Auro GlaxoSmithKline, Brentford, United Kingdom
Simonne Longerich Merck, Kenilworth, NJ, United States
Caroline Fox Merck, Kenilworth, NJ, United States
Anders Mälarstig Pfizer, New York, NY, United States
Katherine Klinger Sanofi, Paris, France
Deepak Raipal Sanofi, Paris, France
Eric Green Maze Therapeutics, San Francisco, CA, United States
Robert Graham Maze Therapeutics, San Francisco, CA, United States
Robert Yang Janssen Biotech, Beerse, Belgium
Richard Siegel Novartis, Basel, Switzerland

University of Helsinki & Biobanks

Tomi Mäkelä HiLIFE, University of Helsinki, Finland, Finland
Jaakko Kaprio Institute for Molecular Medicine Finland, HiLIFE, Helsinki, Finland, Finland
Petri Virolainen Auria Biobank/University of Turku/Hospital District of Southwest Finland, Turku, Finland
Antti Hakanen Auria Biobank/University of Turku/Hospital District of Southwest Finland, Turku, Finland
Terhi Kilpi THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Markus Perola THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Jukka Partanen Finnish Red Cross Blood Service / Finnish Hematology Registry and Clinical Biobank, Helsinki, Finland
Anne Pitkäranta Helsinki Biobank / Helsinki University and Hospital District of Helsinki and Uusimaa, Helsinki
Juhani Junttila Northern Finland Biobank Borealis / University of Oulu / Northern Ostrobothnia Hospital District, Oulu, Finland
Raisa Serpi Northern Finland Biobank Borealis / University of Oulu / Northern Ostrobothnia Hospital District, Oulu, Finland
Tarja Laitinen Finnish Clinical Biobank Tampere / University of Tampere / Pirkanmaa Hospital District, Tampere, Finland
Veli-Matti Kosma Biobank of Eastern Finland / University of Eastern Finland / Northern Savo Hospital District, Kuopio, Finland

Urho Kujala Central Finland Biobank / University of Jyväskylä / Central Finland Health Care District, Jyväskylä, Finland
Marco Hautalahti FINBB - Finnish biobank cooperative

Other Experts/ Non-Voting Members

Outi Tuovila Business Finland, Helsinki, Finland
Raimo Pakkanen Business Finland, Helsinki, Finland

Scientific Committee

Pharmaceutical companies

Jeffrey Waring Abbvie, Chicago, IL, United States
Bridget Riley-Gillis Abbvie, Chicago, IL, United States
Ioanna Tachmazidou Astra Zeneca, Cambridge, United Kingdom
Chia-Yen Chen Biogen, Cambridge, MA, United States
Heiko Runz Biogen, Cambridge, MA, United States
Shameek Biswas Celgene, Summit, NJ, United States/Bristol Myers Squibb, New York, NY, United States
Sarah Pendergrass Genentech, San Francisco, CA, United States
Julie Hunkapiller Genentech, San Francisco, CA, United States
Meg Ehm GlaxoSmithKline, Brentford, United Kingdom
David Pulford GlaxoSmithKline, Brentford, United Kingdom
Neha Raghavan Merck, Kenilworth, NJ, United States
Adriana Huertas-Vazquez Merck, Kenilworth, NJ, United States
Anders Mälarstig Pfizer, New York, NY, United States
Xinli Hu Pfizer, New York, NY, United States
Katherine Klinger Sanofi, Paris, France
Matthias Gossel Sanofi, Paris, France
Robert Graham Maze Therapeutics, San Francisco, CA, United States
Eric Green Maze Therapeutics, San Francisco, CA, United States
Sahar Mozaffari Maze Therapeutics, San Francisco, CA, United States
Dawn Waterworth Janssen Biotech, Beerse, Belgium
Nicole Renaud Novartis, Basel, Switzerland
Ma´en Obeidat Novartis, Basel, Switzerland

University of Helsinki & Biobanks

Samuli Ripatti Institute for Molecular Medicine Finland, HiLIFE, Helsinki, Finland
Johanna Schleutker Auria Biobank / Univ. of Turku / Hospital District of Southwest Finland, Turku, Finland
Markus Perola THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Mikko Arvas Finnish Red Cross Blood Service / Finnish Hematology Registry and Clinical Biobank, Helsinki, Finland
Olli Carpén Helsinki Biobank / Helsinki University and Hospital District of Helsinki and Uusimaa, Helsinki
Reetta Hinttala Northern Finland Biobank Borealis / University of Oulu / Northern Ostrobothnia Hospital District, Oulu, Finland
Johannes Kettunen Northern Finland Biobank Borealis / University of Oulu / Northern Ostrobothnia Hospital District, Oulu, Finland
Arto Mannermaa Biobank of Eastern Finland / University of Eastern Finland / Northern Savo Hospital District, Kuopio, Finland
TBC Finnish Clinical Biobank Tampere / University of Tampere / Pirkanmaa Hospital District, Tampere, Finland
Jari Laukkanen Central Finland Biobank / University of Jyväskylä / Central Finland Health Care District, Jyväskylä, Finland
Urho Kujala Central Finland Biobank / University of Jyväskylä / Central Finland Health Care District, Jyväskylä, Finland

Johanna Mäkelä	FINBB - Finnish biobank cooperative

Clinical Groups

Neurology Group

Reetta Kälviäinen	Northern Savo Hospital District, Kuopio, Finland
Valtteri Julkunen	Northern Savo Hospital District, Kuopio, Finland
Hilkka Soininen	Northern Savo Hospital District, Kuopio, Finland
Anne Remes	Northern Ostrobothnia Hospital District, Oulu, Finland
Mikko Hiltunen	Northern Savo Hospital District, Kuopio, Finland
Jukka Peltola	Pirkanmaa Hospital District, Tampere, Finland
Pentti Tienari	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Juha Rinne	Hospital District of Southwest Finland, Turku, Finland
Roosa Kallionpää	Hospital District of Southwest Finland, Turku, Finland
Ali Abbasi	Abbvie, Chicago, IL, United States
Adam Ziemann	Abbvie, Chicago, IL, United States
Jeffrey Waring	Abbvie, Chicago, IL, United States
Sahar Esmaeeli	Abbvie, Chicago, IL, United States
Nizar Smaoui	Abbvie, Chicago, IL, United States
Anne Lehtonen	Abbvie, Chicago, IL, United States
Susan Eaton	Biogen, Cambridge, MA, United States
Heiko Runz	Biogen, Cambridge, MA, United States
Sanni Lahdenperä	Biogen, Cambridge, MA, United States
Janet van Adelsberg	Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Shameek Biswas	Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Julie Hunkapiller	Genentech, San Francisco, CA, United States
Natalie Bowers	Genentech, San Francisco, CA, United States
Edmond Teng	Genentech, San Francisco, CA, United States
Sarah Pendergrass	Genentech, San Francisco, CA, United States
Onuralp Soylemez	Merck, Kenilworth, NJ, United States
Kari Linden	Pfizer, New York, NY, United States
Fanli Xu	GlaxoSmithKline, Brentford, United Kingdom
David Pulford	GlaxoSmithKline, Brentford, United Kingdom
Kirsi Auro	GlaxoSmithKline, Brentford, United Kingdom
Laura Addis	GlaxoSmithKline, Brentford, United Kingdom
John Eicher	GlaxoSmithKline, Brentford, United Kingdom
Minna Raivio	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Sarah Pendergrass	Genentech, San Francisco, CA, United States
Beryl Cummings	Maze Therapeutics, San Francisco, CA, United States
Juulia Partanen	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Gastroenterology Group

Martti Färkkilä	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Jukka Koskela	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Sampsa Pikkarainen	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Airi Jussila	Pirkanmaa Hospital District, Tampere, Finland
Katri Kaukinen	Pirkanmaa Hospital District, Tampere, Finland
Timo Blomster	Northern Ostrobothnia Hospital District, Oulu, Finland
Mikko Kiviniemi	Northern Savo Hospital District, Kuopio, Finland
Markku Voutilainen	Hospital District of Southwest Finland, Turku, Finland
Ali Abbasi	Abbvie, Chicago, IL, United States
Graham Heap	Abbvie, Chicago, IL, United States
Jeffrey Waring	Abbvie, Chicago, IL, United States
Nizar Smaoui	Abbvie, Chicago, IL, United States
Fedik Rahimov	Abbvie, Chicago, IL, United States

Anne Lehtonen	Abbvie, Chicago, IL, United States
Keith Usiskin	Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Tim Lu	Genentech, San Francisco, CA, United States
Natalie Bowers	Genentech, San Francisco, CA, United States
Danny Oh	Genentech, San Francisco, CA, United States
Sarah Pendergrass	Genentech, San Francisco, CA, United States
Kirsi Kalpala	Pfizer, New York, NY, United States
Melissa Miller	Pfizer, New York, NY, United States
Xinli Hu	Pfizer, New York, NY, United States
Linda McCarthy	GlaxoSmithKline, Brentford, United Kingdom
Onuralp Soylemez	Merck, Kenilworth, NJ, United States
Mark Daly	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Rheumatology Group

Kari Eklund	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Antti Palomäki	Hospital District of Southwest Finland, Turku, Finland
Pia Isomäki	Pirkanmaa Hospital District, Tampere, Finland
Laura Pirilä	Hospital District of Southwest Finland, Turku, Finland
Oili Kaipiainen-Seppänen	Northern Savo Hospital District, Kuopio, Finland
Johanna Huhtakangas	Northern Ostrobothnia Hospital District, Oulu, Finland
Ali Abbasi	Abbvie, Chicago, IL, United States
Jeffrey Waring	Abbvie, Chicago, IL, United States
Fedik Rahimov	Abbvie, Chicago, IL, United States
Apinya Lertratanakul	Abbvie, Chicago, IL, United States
Nizar Smaoui	Abbvie, Chicago, IL, United States
Anne Lehtonen	Abbvie, Chicago, IL, United States
David Close	Astra Zeneca, Cambridge, United Kingdom
Marla Hochfeld	Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Natalie Bowers	Genentech, San Francisco, CA, United States
Sarah Pendergrass	Genentech, San Francisco, CA, United States
Onuralp Soylemez	Merck, Kenilworth, NJ, United States
Kirsi Kalpala	Pfizer, New York, NY, United States
Nan Bing	Pfizer, New York, NY, United States
Xinli Hu	Pfizer, New York, NY, United States
Jorge Esparza Gordillo	GlaxoSmithKline, Brentford, United Kingdom
Kirsi Auro	GlaxoSmithKline, Brentford, United Kingdom
Dawn Waterworth	Janssen Biotech, Beerse, Belgium
Nina Mars	Institute for Molecular Medicine Finland, HiLIFE, Helsinki, Finland

Pulmonology Group

Tarja Laitinen	Pirkanmaa Hospital District, Tampere, Finland
Margit Pelkonen	Northern Savo Hospital District, Kuopio, Finland
Paula Kauppi	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Hannu Kankaanranta	Pirkanmaa Hospital District, Tampere, Finland
Terttu Harju	Northern Ostrobothnia Hospital District, Oulu, Finland
Riitta Lahesmaa	Hospital District of Southwest Finland, Turku, Finland
Nizar Smaoui	Abbvie, Chicago, IL, United States
Alex Mackay	Astra Zeneca, Cambridge, United Kingdom
Glenda Lassi	Astra Zeneca, Cambridge, United Kingdom
Susan Eaton	Biogen, Cambridge, MA, United States
Steven Greenberg	Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Hubert Chen	Genentech, San Francisco, CA, United States
Sarah Pendergrass	Genentech, San Francisco, CA, United States

Natalie Bowers	Genentech, San Francisco, CA, United States
Joanna Betts	GlaxoSmithKline, Brentford, United Kingdom
Soumitra Ghosh	GlaxoSmithKline, Brentford, United Kingdom
Kirsi Auro	GlaxoSmithKline, Brentford, United Kingdom
Rajashree Mishra	GlaxoSmithKline, Brentford, United Kingdom
Sina Rüeger	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Cardiometabolic Diseases Group

Teemu Niiranen	The National Institute of Health and Welfare Helsinki, Finland
Felix Vaura	The National Institute of Health and Welfare Helsinki, Finland
Veikko Salomaa	The National Institute of Health and Welfare Helsinki, Finland
Markus Juonala	Hospital District of Southwest Finland, Turku, Finland
Kaj Metsärinne	Hospital District of Southwest Finland, Turku, Finland
Mika Kähönen	Pirkanmaa Hospital District, Tampere, Finland
Juhani Junttila	Northern Ostrobothnia Hospital District, Oulu, Finland
Markku Laakso	Northern Savo Hospital District, Kuopio, Finland
Jussi Pihlajamäki	Northern Savo Hospital District, Kuopio, Finland
Daniel Gordin	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Juha Sinisalo	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Marja-Riitta Taskinen	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Tiinamaija Tuomi	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Jari Laukkanen	Central Finland Health Care District, Jyväskylä, Finland
Benjamin Challis	Astra Zeneca, Cambridge, United Kingdom
Dirk Paul	Astra Zeneca, Cambridge, United Kingdom
Julie Hunkapiller	Genentech, San Francisco, CA, United States
Natalie Bowers	Genentech, San Francisco, CA, United States
Sarah Pendergrass	Genentech, San Francisco, CA, United States
Onuralp Soylemez	Merck, Kenilworth, NJ, United States
Jaakko Parkkinen	Pfizer, New York, NY, United States
Melissa Miller	Pfizer, New York, NY, United States
Russell Miller	Pfizer, New York, NY, United States
Audrey Chu	GlaxoSmithKline, Brentford, United Kingdom
Kirsi Auro	GlaxoSmithKline, Brentford, United Kingdom
Keith Usiskin	Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Amanda Elliott	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States
Joel Rämö	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Samuli Ripatti	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mary Pat Reeve	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Sanni Ruotsalainen	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Oncology Group

Tuomo Meretoja	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Heikki Joensuu	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Olli Carpén	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Lauri Aaltonen	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Johanna Mattson	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Annika Auranen	Pirkanmaa Hospital District , Tampere, Finland
Peeter Karihtala	Northern Ostrobothnia Hospital District, Oulu, Finland
Saila Kauppila	Northern Ostrobothnia Hospital District, Oulu, Finland
Päivi Auvinen	Northern Savo Hospital District, Kuopio, Finland
Klaus Elenius	Hospital District of Southwest Finland, Turku, Finland
Johanna Schleutker	Hospital District of Southwest Finland, Turku, Finland
Relja Popovic	Abbvie, Chicago, IL, United States
Jeffrey Waring	Abbvie, Chicago, IL, United States

Bridget Riley-Gillis Abbvie, Chicago, IL, United States
Anne Lehtonen Abbvie, Chicago, IL, United States
Jennifer Schutzman Genentech, San Francisco, CA, United States
Julie Hunkapiller Genentech, San Francisco, CA, United States
Natalie Bowers Genentech, San Francisco, CA, United States
Sarah Pendergrass Genentech, San Francisco, CA, United States
Andrey Loboda Merck, Kenilworth, NJ, United States
Aparna Chhibber Merck, Kenilworth, NJ, United States
Heli Lehtonen Pfizer, New York, NY, United States
Stefan McDonough Pfizer, New York, NY, United States
Marika Crohns Sanofi, Paris, France
Sauli Vuoti Sanofi, Paris, France
Diptee Kulkarni GlaxoSmithKline, Brentford, United Kingdom
Kirsi Auro GlaxoSmithKline, Brentford, United Kingdom
Esa Pitkänen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Nina Mars Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mark Daly Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Opthalmology Group

Kai Kaarniranta Northern Savo Hospital District, Kuopio, Finland
Joni A Turunen Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Terhi Ollila Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Sanna Seitsonen Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Hannu Uusitalo Pirkanmaa Hospital District, Tampere, Finland
Vesa Aaltonen Hospital District of Southwest Finland, Turku, Finland
Hannele Uusitalo-Järvinen Pirkanmaa Hospital District, Tampere, Finland
Marja Luodonpää Northern Ostrobothnia Hospital District, Oulu, Finland
Nina Hautala Northern Ostrobothnia Hospital District, Oulu, Finland
Mengzhen Liu Abbvie, Chicago, IL, United States
Heiko Runz Biogen, Cambridge, MA, United States
Stephanie Loomis Biogen, Cambridge, MA, United States
Erich Strauss Genentech, San Francisco, CA, United States
Natalie Bowers Genentech, San Francisco, CA, United States
Hao Chen Genentech, San Francisco, CA, United States
Sarah Pendergrass Genentech, San Francisco, CA, United States
Anna Podgornaia Merck, Kenilworth, NJ, United States
Juha Karjalainen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States
Esa Pitkänen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Dermatology Group

Kaisa Tasanen Northern Ostrobothnia Hospital District, Oulu, Finland
Laura Huilaja Northern Ostrobothnia Hospital District, Oulu, Finland
Katariina Hannula-Jouppi Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Teea Salmi Pirkanmaa Hospital District, Tampere, Finland
Sirkku Peltonen Hospital District of Southwest Finland, Turku, Finland
Leena Koulu Hospital District of Southwest Finland, Turku, Finland
Kirsi Kalpala Pfizer, New York, NY, United States
Ying Wu Pfizer, New York, NY, United States
David Choy Genentech, San Francisco, CA, United States
Sarah Pendergrass Genentech, San Francisco, CA, United States
Nizar Smaoui Abbvie, Chicago, IL, United States
Fedik Rahimov Abbvie, Chicago, IL, United States
Anne Lehtonen Abbvie, Chicago, IL, United States
Dawn Waterworth Janssen Biotech, Beerse, Belgium

Odontology Group

Pirkko Pussinen	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Aino Salminen	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Tuula Salo	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
David Rice	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Pekka Nieminen	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Ulla Palotie	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Juha Sinisalo	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Maria Siponen	Northern Savo Hospital District, Kuopio, Finland
Liisa Suominen	Northern Savo Hospital District, Kuopio, Finland
Päivi Mäntylä	Northern Savo Hospital District, Kuopio, Finland
Ulvi Gursoy	Hospital District of Southwest Finland, Turku, Finland
Vuokko Anttonen	Northern Ostrobothnia Hospital District, Oulu, Finland
Kirsi Sipilä	Northern Ostrobothnia Hospital District, Oulu, Finland
Sarah Pendergrass	Genentech, San Francisco, CA, United States

Women's Health and Reproduction Group

Hannele Laivuori	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Venla Kurra	Pirkanmaa Hospital District, Tampere, Finland
Oskari Heikinheimo	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Ilkka Kalliala	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Laura Kotaniemi-Talonen	Pirkanmaa Hospital District, Tampere, Finland
Kari Nieminen	Pirkanmaa Hospital District, Tampere, Finland
Päivi Polo	Hospital District of Southwest Finland, Turku, Finland
Kaarin Mäkikallio	Hospital District of Southwest Finland, Turku, Finland
Eeva Ekholm	Hospital District of Southwest Finland, Turku, Finland
Marja Vääräsmäki	Northern Ostrobothnia Hospital District, Oulu, Finland
Outi Uimari	Northern Ostrobothnia Hospital District, Oulu, Finland
Laure Morin-Papunen	Northern Ostrobothnia Hospital District, Oulu, Finland
Marjo Tuppurainen	Northern Savo Hospital District, Kuopio, Finland
Katja Kivinen	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Elisabeth Widen	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Taru Tukiainen	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mary Pat Reeve	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mark Daly	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Liu Aoxing	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Eija Laakkonen	University of Jyväskylä, Jyväskylä, Finland
Niko Välimäki	University of Helsinki, Helsinki, Finland
Lauri Aaltonen	Hospital District of Helsinki and Uusimaa, Helsinki, Finland
Johannes Kettunen	Northern Ostrobothnia Hospital District, Oulu, Finland
Mikko Arvas	Finnish Red Cross Blood Service, Helsinki, Finland
Jeffrey Waring	Abbvie, Chicago, IL, United States
Bridget Riley-Gillis	Abbvie, Chicago, IL, United States
Mengzhen Liu	Abbvie, Chicago, IL, United States
Janet Kumar	GlaxoSmithKline, Brentford, United Kingdom
Kirsi Auro	GlaxoSmithKline, Brentford, United Kingdom
Andrea Ganna	Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Sarah Pendergrass	Genentech, San Francisco, CA, United States

FinnGen Analysis working group

Justin Wade Davis	Abbvie, Chicago, IL, United States
Bridget Riley-Gillis	Abbvie, Chicago, IL, United States
Reza Hammond	Abbvie, Chicago, IL, United States
Fedik Rahimov	Abbvie, Chicago, IL, United States
Sahar Esmaeeli	Abbvie, Chicago, IL, United States
Mengzhen Liu	Abbvie, Chicago, IL, United States

Slavé Petrovski Astra Zeneca, Cambridge, United Kingdom
Eleonor Wigmore Astra Zeneca, Cambridge, United Kingdom
Adele Mitchell Biogen, Cambridge, MA, United States
Benjamin Sun Biogen, Cambridge, MA, United States
Ellen Tsai Biogen, Cambridge, MA, United States
Denis Baird Biogen, Cambridge, MA, United States
Paola Bronson Biogen, Cambridge, MA, United States
Ruoyu Tian Biogen, Cambridge, MA, United States
Stephanie Loomis Biogen, Cambridge, MA, United States
Yunfeng Huang Biogen, Cambridge, MA, United States
Joseph Maranville Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Shameek Biswas Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Elmutaz Mohammed Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Samir Wadhawan Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Erika Kvikstad Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Minal Caliskan Celgene, Summit, NJ, United States/ Bristol Myers Squibb, New York, NY, United States
Diana Chang Genentech, San Francisco, CA, United States
Julie Hunkapiller Genentech, San Francisco, CA, United States
Tushar Bhangale Genentech, San Francisco, CA, United States
Natalie Bowers Genentech, San Francisco, CA, United States
Sarah Pendergrass Genentech, San Francisco, CA, United States
Kirill Shkura Merck, Kenilworth, NJ, United States
Victor Neduva Merck, Kenilworth, NJ, United States
Xing Chen Pfizer, New York, NY, United States
Åsa Hedman Pfizer, New York, NY, United States
Karen S King GlaxoSmithKline, Brentford, United Kingdom
Padhraig Gormley GlaxoSmithKline, Brentford, United Kingdom
Jimmy Liu GlaxoSmithKline, Brentford, United Kingdom
Clarence Wang Sanofi, Paris, France
Ethan Xu Sanofi, Paris, France
Franck Auge Sanofi, Paris, France
Clement Chatelain Sanofi, Paris, France
Deepak Rajpal Sanofi, Paris, France
Dongyu Liu Sanofi, Paris, France
Katherine Call Sanofi, Paris, France
Tai-He Xia Sanofi, Paris, France
Beryl Cummings Maze Therapeutics, San Francisco, CA, United States
Matt Brauer Maze Therapeutics, San Francisco, CA, United States
Huilei Xu Novartis, Basel, Switzerland
Amy Cole Novartis, Basel, Switzerland
Jonathan Chung Novartis, Basel, Switzerland
Jaison Jacob Novartis, Basel, Switzerland
Katrina de Lange Novartis, Basel, Switzerland
Jonas Zierer Novartis, Basel, Switzerland
Mitja Kurki Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States
Samuli Ripatti Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mark Daly Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Juha Karjalainen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States

Aki Havulinna Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Juha Mehtonen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Priit Palta Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Shabbeer Hassan Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Pietro Della Briotta Parolo Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Wei Zhou Broad Institute, Cambridge, MA, United States
Mutaamba Maasha Broad Institute, Cambridge, MA, United States
Shabbeer Hassan Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Susanna Lemmelä Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Manuel Rivas University of Stanford, Stanford, CA, United States
Aarno Palotie Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Arto Lehisto Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Andrea Ganna Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Vincent Llorens Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Hannele Laivuori Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mari E Niemi Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Taru Tukiainen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mary Pat Reeve Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Henrike Heyne Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Nina Mars Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Kimmo Palin University of Helsinki, Helsinki, Finland
Javier Garcia-Tabuenca University of Tampere, Tampere, Finland
Harri Siirtola University of Tampere, Tampere, Finland
Tuomo Kiiskinen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Jiwoo Lee Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States
Kristin Tsuo Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States
Amanda Elliott Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States
Kati Kristiansson THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Mikko Arvas Finnish Red Cross Blood Service / Finnish Hematology Registry and Clinical Biobank, Helsinki, Finland
Kati Hyvärinen Finnish Red Cross Blood Service, Helsinki, Finland
Jarmo Ritari Finnish Red Cross Blood Service, Helsinki, Finland
Miika Koskinen Helsinki Biobank / Helsinki University and Hospital District of Helsinki and Uusimaa, Helsinki
Olli Carpén Helsinki Biobank / Helsinki University and Hospital District of Helsinki and Uusimaa, Helsinki
Johannes Kettunen Northern Finland Biobank Borealis / University of Oulu / Northern Ostrobothnia Hospital District, Oulu, Finland
Katri Pylkäs University of Oulu, Oulu, Finland
Eeva Sliz University of Oulu, Oulu, Finland
Minna Karjalainen University of Oulu, Oulu, Finland
Tuomo Mantere Northern Finland Biobank Borealis / University of Oulu / Northern Ostrobothnia Hospital District, Oulu, Finland
Eeva Kangasniemi Finnish Clinical Biobank Tampere / University of Tampere / Pirkanmaa Hospital District, Tampere, Finland
Sami Heikkinen University of Eastern Finland, Kuopio, Finland
Arto Mannermaa Biobank of Eastern Finland / University of Eastern Finland / Northern Savo Hospital District, Kuopio, Finland
Eija Laakkonen University of Jyväskylä, Jyväskylä, Finland
Samuel Heron University of Turku, Turku, Finland
Dhanaprakash Jambulingam University of Turku, Turku, Finland
Venkat Subramaniam Rathinakannan University of Turku, Turku, Finland

Nina Pitkänen Auria Biobank / University of Turku / Hospital District of Southwest Finland, Turku, Finland

Biobank directors

Lila Kallio Auria Biobank / University of Turku / Hospital District of Southwest Finland, Turku, Finland
Sirpa Soini THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Jukka Partanen Finnish Red Cross Blood Service / Finnish Hematology Registry and Clinical Biobank, Helsinki, Finland
Eero Punkka Helsinki Biobank / Helsinki University and Hospital District of Helsinki and Uusimaa, Helsinki
Raisa Serpi Northern Finland Biobank Borealis / University of Oulu / Northern Ostrobothnia Hospital District, Oulu, Finland
TBC Finnish Clinical Biobank Tampere / University of Tampere / Pirkanmaa Hospital District, Tampere, Finland
Veli-Matti Kosma Biobank of Eastern Finland / University of Eastern Finland / Northern Savo Hospital District, Kuopio, Finland
Teijo Kuopio Central Finland Biobank / University of Jyväskylä / Central Finland Health Care District, Jyväskylä, Finland

FinnGen Teams

Administration

Anu Jalanko Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Huei-Yi Shen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Risto Kajanne Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mervi Aavikko Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Analysis

Mitja Kurki Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States
Juha Karjalainen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland / Broad Institute, Cambridge, MA, United States
Pietro Della Briotta Parolo Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Arto Lehisto Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Juha Mehtonen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Wei Zhou Broad Institute, Cambridge, MA, United States
Masahiro Kanai Broad Institute, Cambridge, MA, United States
Mutaamba Maasha Broad Institute, Cambridge, MA, United States

Clinical Endpoint Development

Hannele Laivuori Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Aki Havulinna Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Susanna Lemmelä Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Tuomo Kiiskinen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
L. Elisa Lahtela Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Communication

Mari Kaunisto Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

E-Science

Elina Kilpeläinen Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Timo P. Sipilä Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Georg Brein Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Oluwaseun Alexander Dada Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Awaisa Ghazal Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Anastasia Shcherban Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Genotyping
Kati Donner Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Timo P. Sipilä Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Sample Collection Coordination
Anu Loukola Helsinki Biobank / Helsinki University and Hospital District of Helsinki and Uusimaa, Helsinki

Sample Logistics
Päivi Laiho THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Tuuli Sistonen THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Essi Kaiharju THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Markku Laukkanen THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Elina Järvensivu THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Sini Lähteenmäki THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Lotta Männikkö THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Regis Wong THL Biobank / The National Institute of Health and Welfare Helsinki, Finland

Registry Data Operations
Hannele Mattsson THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Kati Kristiansson THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Susanna Lemmelä Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Sami Koskelainen THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Tero Hiekkalinna THL Biobank / The National Institute of Health and Welfare Helsinki, Finland
Teemu Paajanen THL Biobank / The National Institute of Health and Welfare Helsinki, Finland

Sequencing Informatics
Priit Palta Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Kalle Pärn Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Mart Kals Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Shuang Luo Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Vishal Sinha Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

Trajectory
Tarja Laitinen Pirkanmaa Hospital District, Tampere, Finland
Mary Pat Reeve Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland
Harri Siirtola University of Tampere, Tampere, Finland
Javier Gracia-Tabuenca University of Tampere, Tampere, Finland
Mika Helminen University of Tampere, Tampere, Finland
Tiina Luukkaala University of Tampere, Tampere, Finland
Iida Vähätalo University of Tampere, Tampere, Finland

Data protection officer
Tero Jyrhämä Institute for Molecular Medicine Finland, HiLIFE, University of Helsinki, Finland

FINBB - Finnish biobank cooperative
Marco Hautalahti
Johanna Mäkelä
Laura Mustaniemi

Mirkka Koivusalo
Sarah Smith
Tom Southerington

Bibliography for Supplementary Data 7. Each reference starts with the PMID before a colon. The references are sorted by their PMIDs.

1. 2307: Sakakibara, S., Yamaguchi, K., Hosokawa, Y., Kohashi, N. & Ueda, I. Purification and some properties of rat liver cysteine oxidase (cysteine dioxygenase). *Biochim Biophys Acta* **422,** 273–279 (1976).
2. 8453: Enoch, H. G., Catalá, A. & Strittmatter, P. Mechanism of rat liver microsomal stearyl-CoA desaturase. Studies of the substrate specificity, enzyme-substrate interactions, and the function of lipid. *J Biol Chem* **251,** 5095–5103 (1976).
3. 17401: Vessey, D. A. & Zakim, D. Characterization of microsomal choloyl-coenzyme A synthetase. *Biochem J* **163,** 357–362 (1977).
4. 33715: Fluharty, A. L., Stevens, R. L., Goldstein, E. B. & Kihara, H. The activity of arylsulfatase A and B on tyrosine O-sulfates. *Biochim Biophys Acta* **566,** 321–326 (1979).
5. 218932: Spector, T., Jones, T. E. & Miller, R. L. Reaction mechanism and specificity of human GMP reductase. Substrates, inhibitors, activators, and inactivators. *J Biol Chem* **254,** 2308–2315 (1979).
6. 226968: Brown, M. S. & Goldstein, J. L. Receptor-mediated endocytosis: insights from the lipoprotein receptor system. *Proc Natl Acad Sci U S A* **76,** 3330–3337 (1979).
7. 240826: Spector, T. Studies with GMP synthetase from Ehrlich ascites cells. Purification, properties, and interactions with nucleotide analogs. *J Biol Chem* **250,** 7372–7376 (1975).
8. 873932: Lindblad, B., Lindstedt, G., Lindstedt, S. & Rundgren, M. Purification and some properties of human 4-hydroxyphenylpyruvate dioxygenase (I). *J Biol Chem* **252,** 5073–5084 (1977).
9. 1281977: Rip, J. W., Coulter-Mackie, M. B., Rupar, C. A. & Gordon, B. A. Purification and structure of human liver aspartylglucosaminidase. *Biochem J* **288 (Pt 3),** 1005–1010 (1992).
10. 1302044: Gu, L., Gonzalez, F. J., Kalow, W. & Tang, B. K. Biotransformation of caffeine, paraxanthine, theobromine and theophylline by cDNA-expressed human CYP1A2 and CYP2E1. *Pharmacogenetics* **2,** 73–77 (1992).
11. 1550553: Carpenter, K., Pollitt, R. J. & Middleton, B. Human liver long-chain 3-hydroxyacyl-coenzyme A dehydrogenase is a multifunctional membrane-bound beta-oxidation enzyme of mitochondria. *Biochem Biophys Res Commun* **183,** 443–448 (1992).
12. 1730632: Izai, K., Uchida, Y., Orii, T., Yamamoto, S. & Hashimoto, T. Novel fatty acid beta-oxidation enzymes in rat liver mitochondria. I. Purification and properties of very-long-chain acyl-coenzyme A dehydrogenase. *J Biol Chem* **267,** 1027–1033 (1992).
13. 1865762: Gavino, G. R. & Gavino, V. C. Rat liver outer mitochondrial carnitine palmitoyltransferase activity towards long-chain polyunsaturated fatty acids and their CoA esters. *Lipids* **26,** 266–270 (1991).
14. 1973834: Rettenmeier, R., Natt, E., Zentgraf, H. & Scherer, G. Isolation and characterization of the human tyrosine aminotransferase gene. *Nucleic Acids Res* **18,** 3853–3861 (1990).
15. 1999428: Melkerson-Watson, L. J. & Sweeley, C. C. Purification to apparent homogeneity by immunoaffinity chromatography and partial characterization of the GM3 ganglioside-forming enzyme, CMP-sialic acid:lactosylceramide alpha 2,3-sialyltransferase (SAT-1), from rat liver Golgi. *J Biol Chem* **266,** 4448–4457 (1991).
16. 2157703: Höglund, L. & Reichard, P. Cytoplasmic 5'(3')-nucleotidase from human placenta. *J Biol Chem* **265,** 6589–6595 (1990).
17. 2211729: Small, W. C. & Jones, M. E. Pyrroline 5-carboxylate dehydrogenase of the mitochondrial matrix of rat liver. Purification, physical and kinetic characteristics. *J Biol Chem* **265,** 18668–18672 (1990).
18. 2340092: Chang, C. Y., Wu, D. A., Mohandas, T. K. & Chung, B. C. Structure, sequence, chromosomal location, and evolution of the human ferredoxin gene family. *DNA Cell Biol* **9,** 205–212 (1990).
19. 2351134: Bloisi, W. *et al.* Purification and properties of carnitine acetyltransferase from human liver. *Eur J Biochem* **189,** 539–546 (1990).
20. 2444024: Rask, L., Anundi, H., Fohlman, J. & Peterson, P. A. The complete amino acid sequence of human serum retinol-binding protein. *Ups J Med Sci* **92,** 115–146 (1987).

21. 2463916: Schoedon, G., Redweik, U. & Curtius, H. C. Purification of GTP cyclohydrolase I from human liver and production of specific monoclonal antibodies. *Eur J Biochem* **178,** 627–634 (1989).
22. 2917560: Van Schaftingen, E. A protein from rat liver confers to glucokinase the property of being antagonistically regulated by fructose 6-phosphate and fructose 1-phosphate. *Eur J Biochem* **179,** 179–184 (1989).
23. 2993784: Andersson, S., Boström, H., Danielsson, H. & Wikvall, K. Purification from rabbit and rat liver of cytochromes P-450 involved in bile acid biosynthesis. *Methods Enzymol* **111,** 364–377 (1985).
24. 3081514: Lenich, A. C. & Goodman, S. I. The purification and characterization of glutaryl-coenzyme A dehydrogenase from porcine and human liver. *J Biol Chem* **261,** 4090–4096 (1986).
25. 3094014: Flink, I. L., Bailey, T. J., Gustafson, T. A., Markham, B. E. & Morkin, E. Complete amino acid sequence of human thyroxine-binding globulin deduced from cloned DNA: close homology to the serine antiproteases. *Proc Natl Acad Sci U S A* **83,** 7708–7712 (1986).
26. 3299377: Hammond, G. L. *et al.* Primary structure of human corticosteroid binding globulin, deduced from hepatic and pulmonary cDNAs, exhibits homology with serine protease inhibitors. *Proc Natl Acad Sci U S A* **84,** 5153–5157 (1987).
27. 3346674: Blakely, R. D., Robinson, M. B., Thompson, R. C. & Coyle, J. T. Hydrolysis of the brain dipeptide N-acetyl-L-aspartyl-L-glutamate: subcellular and regional distribution, ontogeny, and the effect of lesions on N-acetylated-alpha-linked acidic dipeptidase activity. *J Neurochem* **50,** 1200–1209 (1988).
28. 3365415: Maret, W. & Auld, D. S. Purification and characterization of human liver sorbitol dehydrogenase. *Biochemistry* **27,** 1622–1628 (1988).
29. 3473473: Fischer, W. H. & Spiess, J. Identification of a mammalian glutaminyl cyclase converting glutaminyl into pyroglutamyl peptides. *Proc Natl Acad Sci U S A* **84,** 3628–3632 (1987).
30. 3521732: Chung, D. W., Fujikawa, K., McMullen, B. A. & Davie, E. W. Human plasma prekallikrein, a zymogen to a serine protease that contains four tandem repeats. *Biochemistry* **25,** 2410–2417 (1986).
31. 3532105: Weiss, M. J. *et al.* Isolation and characterization of a cDNA encoding a human liver/bone/kidney-type alkaline phosphatase. *Proc Natl Acad Sci U S A* **83,** 7182–7186 (1986).
32. 3540966: Haraguchi, Y. *et al.* Molecular cloning and nucleotide sequence of cDNA for human liver arginase. *Proc Natl Acad Sci U S A* **84,** 412–415 (1987).
33. 3558558: van den Berg, G. A., Kingma, A. W., Elzinga, H. & Muskiet, F. A. Determination of N-(3-acetamidopropyl)pyrrolidin-2-one, a metabolite of spermidine, in urine by isotope dilution mass fragmentography. *J Chromatogr* **383,** 251–258 (1986).
34. 3597357: Finocchiaro, G., Ito, M. & Tanaka, K. Purification and properties of short chain acyl-CoA, medium chain acyl-CoA, and isovaleryl-CoA dehydrogenases from human liver. *J Biol Chem* **262,** 7982–7989 (1987).
35. 3800397: Gross, M. D., Eggen, M. A., Simon, A. M. & Van Pilsum, J. F. The purification and characterization of human kidney L-arginine:glycine amidinotransferase. *Arch Biochem Biophys* **251,** 747–755 (1986).
36. 4150152: Kaufman, S. The phenylalanine hydroxylating system from mammalian liver. *Adv Enzymol Relat Areas Mol Biol* **35,** 245–319 (1971).
37. 4373031: Weinhold, P. A. & Rethy, V. B. The separation, purification, and characterization of ethanolamine kinase and choline kinase from rat liver. *Biochemistry* **13,** 5135–5141 (1974).
38. 4389188: Okamoto, H. & Hayaishi, O. Solubilization and partial purification of kynurenine hydroxylase from mitochondrial outer membrane and its electron donors. *Arch Biochem Biophys* **131,** 603–608 (1969).
39. 4402936: Bosron, W. F. & Prairie, R. L. Triphosphopyridine nucleotide-linked aldehyde reductase. I. Purification and properties of the enzyme from pig kidney cortex. *J Biol Chem* **247,** 4480–4485 (1972).
40. 4585091: Kikuchi, G. The glycine cleavage system: composition, reaction mechanism, and physiological significance. *Mol Cell Biochem* **1,** 169–187 (1973).
41. 4607556: Kanda, Y., Goodman, D. S., Canfield, R. E. & Morgan, F. J. The amino acid sequence of human plasma prealbumin. *J Biol Chem* **249,** 6796–6805 (1974).
42. 4621658: Hiles, R. A. & Henderson, L. M. The partial purification and properties of hydroxylysine kinase from rat liver. *J Biol Chem* **247,** 646–651 (1972).

43. 4623131: Shrawder, E. & Martinez-Carrion, M. Evidence of phenylalanine transaminase activity in the isoenzymes of aspartate transaminase. *J Biol Chem* **247,** 2486–2492 (1972).
44. 4981785: Jost, J. P. & Bock, R. M. Enzymatic hydrolysis of N-substituted aminoacyl transfer ribonucleic acid in yeast. *J Biol Chem* **244,** 5866–5873 (1969).
45. 4990629: Sanada, Y., Suemori, I. & Katunuma, N. Properties of ornithine aminotransferase from rat liver, kidney and small intestine. *Biochim Biophys Acta* **220,** 42–50 (1970).
46. 5044040: Krenitsky, T. A., Neil, S. M., Elion, G. B. & Hitchings, G. H. A comparison of the specificities of xanthine oxidase and aldehyde oxidase. *Arch Biochem Biophys* **150,** 585–599 (1972).
47. 5432795: Lowy, B. & Dorfman, B. Z. Adenylosuccinase activity in human and rabbit erythrocyte lysates. *J Biol Chem* **245,** 3043–3046 (1970).
48. 5773299: Kakimoto, Y., Taniguchi, K. & Sano, I. D-beta-aminoisobutyrate:pyruvate aminotransferase in mammalian liver and excretion of beta-aminoisobutyrate by man. *J Biol Chem* **244,** 335–340 (1969).
49. 6122685: Kozak, E. M. & Tate, S. S. Glutathione-degrading enzymes of microvillus membranes. *J Biol Chem* **257,** 6322–6327 (1982).
50. 6130452: Butler, J. D. & Spielberg, S. P. Accumulation of cystine from glutathione-cysteine mixed disulfide in cystinotic fibroblasts; blockade by an inhibitor of gamma-glutamyl transpeptidase. *Life Sci* **31,** 2563–2570 (1982).
51. 6194510: Bock, H. G., Su, T. S., O'Brien, W. E. & Beaudet, A. L. Sequence for human argininosuccinate synthetase cDNA. *Nucleic Acids Res* **11,** 6505–6512 (1983).
52. 6432877: Yamamoto, S., Yoshimoto, T., Furukawa, M., Horie, T. & Watanabe-Kohno, S. Arachidonate 5-lipoxygenase and its new inhibitors. *J Allergy Clin Immunol* **74,** 349–352 (1984).
53. 6457829: Reitman, M. L. & Kornfeld, S. Lysosomal enzyme targeting. N-Acetylglucosaminylphosphotransferase selectively phosphorylates native lysosomal enzymes. *J Biol Chem* **256,** 11977–11980 (1981).
54. 6772170: Sachan, D. S. & Hoppel, C. L. Carnitine biosynthesis. Hydroxylation of N6-trimethyl-lysine to 3-hydroxy-N6-trimethyl-lysine. *Biochem J* **188,** 529–534 (1980).
55. 6893554: McClard, R. W., Black, M. J., Livingstone, L. R. & Jones, M. E. Isolation and initial characterization of the single polypeptide that synthesizes uridine 5'-monophosphate from orotate in Ehrlich ascites carcinoma. Purification by tandem affinity chromatography of uridine-5'-monophosphate synthase. *Biochemistry* **19,** 4699–4706 (1980).
56. 7284378: Desgranges, C., Razaka, G., Rabaud, M. & Bricaud, H. Catabolism of thymidine in human blood platelets: purification and properties of thymidine phosphorylase. *Biochim Biophys Acta* **654,** 211–218 (1981).
57. 7360517: Goodman, S. I., McCabe, E. R., Fennessey, P. V. & Mace, J. W. Multiple acyl-CoA dehydrogenase deficiency (glutaric aciduria type II) with transient hypersarcosinemia and sarcosinuria; possible inherited deficiency of an electron transfer flavoprotein. *Pediatr Res* **14,** 12–17 (1980).
58. 7417375: Kuusi, T., Saarinen, P. & Nikkilä, E. A. Evidence for the role of hepatic endothelial lipase in the metabolism of plasma high density lipoprotein2 in man. *Atherosclerosis* **36,** 589–593 (1980).
59. 7488099: Watanabe, S. & Uchida, T. Cloning and expression of human uridine phosphorylase. *Biochem Biophys Res Commun* **216,** 265–272 (1995).
60. 7564244: Wanders, R. J. & Mooyer, P. D-2-hydroxyglutaric acidaemia: identification of a new enzyme, D-2-hydroxyglutarate dehydrogenase, localized in mitochondria. *J Inherit Metab Dis* **18,** 194–196 (1995).
61. 7608105: Kimoto, M., Whitley, G. S., Tsuji, H. & Ogawa, T. Detection of NG,NG-dimethylarginine dimethylaminohydrolase in human tissues using a monoclonal antibody. *J Biochem* **117,** 237–238 (1995).
62. 7639524: Luo, M. J., Mao, L. F. & Schulz, H. Short-chain 3-hydroxy-2-methylacyl-CoA dehydrogenase from rat liver: purification and characterization of a novel enzyme of isoleucine metabolism. *Arch Biochem Biophys* **321,** 214–220 (1995).
63. 7690140: Markovich, D., Forgo, J., Stange, G., Biber, J. & Murer, H. Expression cloning of rat renal Na+/SO4(2-) cotransport. *Proc Natl Acad Sci U S A* **90,** 8073–8077 (1993).

64. 7702556: Krupenko, S. A., Wagner, C. & Cook, R. J. Recombinant 10-formyltetrahydrofolate dehydrogenase catalyses both dehydrogenase and hydrolase reactions utilizing the synthetic substrate 10-formyl-5,8-dideazafolate. *Biochem J* **306 (Pt 3),** 651–655 (1995).
65. 7704034: Goldstein, J. A. & de Morais, S. M. Biochemistry and molecular biology of the human CYP2C subfamily. *Pharmacogenetics* **4,** 285–299 (1994).
66. 7734398: Levy, M. A. *et al.* Cloning, expression and functional characterization of type 1 and type 2 steroid 5 alpha-reductases from Cynomolgus monkey: comparisons with human and rat isoenzymes. *J Steroid Biochem Mol Biol* **52,** 307–319 (1995).
67. 7773568: Dawson, P. A. & Oelkers, P. Bile acid transporters. *Curr Opin Lipidol* **6,** 109–114 (1995).
68. 7860756: Shneider, B. L. *et al.* Cloning and molecular characterization of the ontogeny of a rat ileal sodium-dependent bile acid transporter. *J Clin Invest* **95,** 745–754 (1995).
69. 7896285: Hofmann, K., Düker, M., Fink, T., Lichter, P. & Stoffel, W. Human neutral amino acid transporter ASCT1: structure of the gene (SLC1A4) and localization to chromosome 2p13-p15. *Genomics* **24,** 20–26 (1994).
70. 7957888: Hooper, N. M. Families of zinc metalloproteases. *FEBS Lett* **354,** 1–6 (1994).
71. 8083224: Yokota, H. *et al.* cDNA cloning and chromosome mapping of human dihydropyrimidine dehydrogenase, an enzyme associated with 5-fluorouracil toxicity and congenital thymine uraciluria. *J Biol Chem* **269,** 23192–23196 (1994).
72. 8093002: Veronese, M. E., Burgess, W., Zhu, X. & McManus, M. E. Functional characterization of two human sulphotransferase cDNAs that encode monoamine- and phenol-sulphating forms of phenol sulphotransferase: substrate kinetics, thermal-stability and inhibitor-sensitivity studies. *Biochem J* **302 (Pt 2),** 497–502 (1994).
73. 8095225: Eugster, H. P., Probst, M., Würgler, F. E. & Sengstag, C. Caffeine, estradiol, and progesterone interact with human CYP1A1 and CYP1A2. Evidence from cDNA-directed expression in Saccharomyces cerevisiae. *Drug Metab Dispos* **21,** 43–49 (1993).
74. 8117268: Aoyama, T. *et al.* Molecular cloning and functional expression of a human peroxisomal acyl-coenzyme A oxidase. *Biochem Biophys Res Commun* **198,** 1113–1118 (1994).
75. 8198549: Petronini, P. G., De Angelis, E., Borghetti, A. F. & Wheeler, K. P. Osmotically inducible uptake of betaine via amino acid transport system A in SV-3T3 cells. *Biochem J* **300 (Pt 1),** 45–50 (1994).
76. 8241290: Jansen, G. A. & Wanders, R. J. L-2-hydroxyglutarate dehydrogenase: identification of a novel enzyme activity in rat and human liver. Implications for L-2-hydroxyglutaric acidemia. *Biochim Biophys Acta* **1225,** 53–56 (1993).
77. 8399210: Chen, F. *et al.* Characterization of a cloned human dihydrotestosterone/androstanediol UDP-glucuronosyltransferase and its comparison to other steroid isoforms. *Biochemistry* **32,** 10648–10657 (1993).
78. 8422236: Kühn, K., Bertling, W. M. & Emmrich, F. Cloning of a functional cDNA for human cytidine deaminase (CDD) and its use as a marker of monocyte/macrophage differentiation. *Biochem Biophys Res Commun* **190,** 1–7 (1993).
79. 8427875: Kontani, Y., Kaneko, M., Kikugawa, M., Fujimoto, S. & Tamaki, N. Identity of D-3-aminoisobutyrate-pyruvate aminotransferase with alanine-glyoxylate aminotransferase 2. *Biochim Biophys Acta* **1156,** 161–166 (1993).
80. 8486162: Kilponen, J. M. & Hiltunen, J. K. Beta-oxidation of unsaturated fatty acids in humans. Isoforms of delta 3, delta 2-enoyl-CoA isomerase. *FEBS Lett* **322,** 299–303 (1993).
81. 8575776: Durocher, F., Morissette, J., Dufort, I., Simard, J. & Luu-The, V. Genetic linkage mapping of the dehydroepiandrosterone sulfotransferase (STD) gene on the chromosome 19q13.3 region. *Genomics* **29,** 781–783 (1995).
82. 8640791: Jedlitschky, G. *et al.* Transport of glutathione, glucuronate, and sulfate conjugates by the MRP gene-encoded conjugate export pump. *Cancer Res* **56,** 988–994 (1996).
83. 8725270: Corydon, M. J. *et al.* Ethylmalonic aciduria is associated with an amino acid variant of short chain acyl-coenzyme A dehydrogenase. *Pediatr Res* **39,** 1059–1066 (1996).
84. 8798461: Garrow, T. A. Purification, kinetic properties, and cDNA cloning of mammalian betaine-homocysteine methyltransferase. *J Biol Chem* **271,** 22831–22838 (1996).
85. 8798464: Beaulieu, M., Lévesque, E., Hum, D. W. & Bélanger, A. Isolation and characterization of a novel cDNA encoding a human UDP-glucuronosyltransferase active on C19 steroids. *J Biol Chem* **271,** 22855–22862 (1996).

86. 8858963: Sastre, M., Regunathan, S., Galea, E. & Reis, D. J. Agmatinase activity in rat brain: a metabolic pathway for the degradation of agmatine. *J Neurochem* **67,** 1761–1765 (1996).
87. 9124315: Ritzel, M. W. *et al.* Molecular cloning and functional expression of cDNAs encoding a human Na+-nucleoside cotransporter (hCNT1). *Am J Physiol* **272,** C707-714 (1997).
88. 9188469: Cupillard, L., Koumanov, K., Mattéi, M. G., Lazdunski, M. & Lambeau, G. Cloning, chromosomal mapping, and expression of a novel human secretory phospholipase A2. *J Biol Chem* **272,** 15745–15752 (1997).
89. 9233839: Srivenugopal, K. S. & Ali-Osman, F. Activity and distribution of the cysteine prodrug activating enzyme, 5-oxo-L-prolinase, in human normal and tumor tissues. *Cancer Lett* **117,** 105–111 (1997).
90. 9252398: Alperin, E. S. & Shapiro, L. J. Characterization of point mutations in patients with X-linked ichthyosis. Effects on the structure and function of the steroid sulfatase protein. *J Biol Chem* **272,** 20756–20763 (1997).
91. 9452426: Auchus, R. J., Lee, T. C. & Miller, W. L. Cytochrome b5 augments the 17,20-lyase activity of human P450c17 without direct electron transfer. *J Biol Chem* **273,** 3158–3165 (1998).
92. 9516450: Prasad, P. D. *et al.* Cloning and functional expression of a cDNA encoding a mammalian sodium-dependent vitamin transporter mediating the uptake of pantothenate, biotin, and lipoate. *J Biol Chem* **273,** 7501–7506 (1998).
93. 9544928: Henriksen, C. M., Nielsen, J. & Villadsen, J. Cyclization of alpha-aminoadipic acid into the the delta-lactam 6-oxo-piperidine-2-carboxylic acid by Penicillium chrysogenum. *J Antibiot (Tokyo)* **51,** 99–106 (1998).
94. 9575212: Sugimoto, H., Odani, S. & Yamashita, S. Cloning and expression of cDNA encoding rat liver 60-kDa lysophospholipase containing an asparaginase-like region and ankyrin repeat. *J Biol Chem* **273,** 12536–12542 (1998).
95. 9647737: Dousset, B. *et al.* Purification from human plasma of a hexapeptide that potentiates the sulfation and mitogenic activities of insulin-like growth factors. *Biochem Biophys Res Commun* **247,** 587–591 (1998).
96. 9654057: Ventura, F. V. *et al.* Carnitine palmitoyltransferase II specificity towards beta-oxidation intermediates--evidence for a reverse carnitine cycle in mitochondria. *Eur J Biochem* **253,** 614–618 (1998).
97. 9924800: Schenk, G., Duggleby, R. G. & Nixon, P. F. Properties and functions of the thiamin diphosphate dependent enzyme transketolase. *Int J Biochem Cell Biol* **30,** 1297–1318 (1998).
98. 9925947: Blackburn, A. C., Woollatt, E., Sutherland, G. R. & Board, P. G. Characterization and chromosome location of the gene GSTZ1 encoding the human Zeta class glutathione transferase and maleylacetoacetate isomerase. *Cytogenet Cell Genet* **83,** 109–114 (1998).
99. 10102904: Moolenaar, S. H. *et al.* Defect in dimethylglycine dehydrogenase, a new inborn error of metabolism: NMR spectroscopy study. *Clin Chem* **45,** 459–464 (1999).
100. 10329726: Hirohashi, T., Suzuki, H. & Sugiyama, Y. Characterization of the transport properties of cloned rat multidrug resistance-associated protein 3 (MRP3). *J Biol Chem* **274,** 15181–15185 (1999).
101. 10419495: Geisbrecht, B. V., Zhang, D., Schulz, H. & Gould, S. J. Characterization of PECI, a novel monofunctional Delta(3), Delta(2)-enoyl-CoA isomerase of mammalian peroxisomes. *J Biol Chem* **274,** 21797–21803 (1999).
102. 10441143: Brix, L. A., Barnett, A. C., Duggleby, R. G., Leggett, B. & McManus, M. E. Analysis of the substrate specificity of human sulfotransferases SULT1A1 and SULT1A3: site-directed mutagenesis and kinetic studies. *Biochemistry* **38,** 10474–10479 (1999).
103. 10471399: Rajan, D. P. *et al.* Human placental sodium-dependent vitamin C transporter (SVCT2): molecular cloning and transport function. *Biochem Biophys Res Commun* **262,** 762–768 (1999).
104. 10556521: Daruwala, R., Song, J., Koh, W. S., Rumsey, S. C. & Levine, M. Cloning and functional characterization of the human sodium-dependent vitamin C transporters hSVCT1 and hSVCT2. *FEBS Lett* **460,** 480–484 (1999).
105. 10588648: Pfeiffer, R. *et al.* Luminal heterodimeric amino acid transporter defective in cystinuria. *Mol Biol Cell* **10,** 4135–4147 (1999).
106. 10605936: Nebert, D. W. *et al.* Role of the aromatic hydrocarbon receptor and [Ah] gene battery in the oxidative stress response, cell cycle control, and apoptosis. *Biochem Pharmacol* **59,** 65–85 (2000).

107. 10620514: Gómez-Fabre, P. M. *et al.* Molecular cloning, sequencing and expression studies of the human breast cancer cell glutaminase. *Biochem J* **345 Pt 2,** 365–375 (2000).
108. 10744128: Gross, M. *et al.* Distribution and concordance of N-acetyltransferase genotype and phenotype in an American population. *Cancer Epidemiol Biomarkers Prev* **8,** 683–692 (1999).
109. 10748143: Kojima, Y. *et al.* Molecular cloning of globotriaosylceramide/CD77 synthase, a glycosyltransferase that initiates the synthesis of globo series glycosphingolipids. *J Biol Chem* **275,** 15152–15156 (2000).
110. 10777549: Jones, J. M., Morrell, J. C. & Gould, S. J. Identification and characterization of HAOX1, HAOX2, and HAOX3, three human peroxisomal 2-hydroxy acid oxidases. *J Biol Chem* **275,** 12590–12597 (2000).
111. 10794676: Wang, H. *et al.* Structure, function, and genomic organization of human Na(+)-dependent high-affinity dicarboxylate transporter. *Am J Physiol Cell Physiol* **278,** C1019-1030 (2000).
112. 10802064: Nava, V. E. *et al.* Functional characterization of human sphingosine kinase-1. *FEBS Lett* **473,** 81–84 (2000).
113. 10829015: Zimmer, S. *et al.* A novel human tocopherol-associated protein: cloning, in vitro expression, and characterization. *J Biol Chem* **275,** 25672–25680 (2000).
114. 10843803: Chen, Y. M. *et al.* Genomic structure, expression, and chromosomal localization of the human glycine N-methyltransferase gene. *Genomics* **66,** 43–47 (2000).
115. 10859351: Mandala, S. M. *et al.* Molecular cloning and characterization of a lipid phosphohydrolase that degrades sphingosine-1- phosphate and induces cell death. *Proc Natl Acad Sci U S A* **97,** 7859–7864 (2000).
116. 10860550: Kawashima, H. *et al.* Human fatty acid omega-hydroxylase, CYP4A11: determination of complete genomic sequence and characterization of purified recombinant protein. *Arch Biochem Biophys* **378,** 333–339 (2000).
117. 10860662: Marquardt, A., Stöhr, H., White, K. & Weber, B. H. cDNA cloning, genomic structure, and chromosomal localization of three members of the human fatty acid desaturase family. *Genomics* **66,** 175–183 (2000).
118. 10903140: Bröer, A., Wagner, C. A., Lang, F. & Bröer, S. The heterodimeric amino acid transporter 4F2hc/y+LAT2 mediates arginine efflux in exchange with glutamine. *Biochem J* **349 Pt 3,** 787–795 (2000).
119. 11067870: Schwarz, M. *et al.* The bile acid synthetic gene 3beta-hydroxy-Delta(5)-C(27)-steroid oxidoreductase is mutated in progressive intrahepatic cholestasis. *J Clin Invest* **106,** 1175–1184 (2000).
120. 11102558: Zschocke, J. *et al.* Progressive infantile neurodegeneration caused by 2-methyl-3-hydroxybutyryl-CoA dehydrogenase deficiency: a novel inborn error of branched-chain fatty acid and isoleucine metabolism. *Pediatr Res* **48,** 852–855 (2000).
121. 11248200: Akita, H. *et al.* Characterization of bile acid transport mediated by multidrug resistance associated protein 2 and bile salt export pump. *Biochim Biophys Acta* **1511,** 7–16 (2001).
122. 11279164: Lowenson JD, Kim E, Young SG, & Clarke, S. Limited accumulation of damaged proteins in l-isoaspartyl (D-aspartyl) O-methyltransferase-deficient mice. *J Biol Chem* **276**: 20695-702 (2001).
123. 11302742: Ichida, K., Matsumura, T., Sakuma, R., Hosoya, T. & Nishino, T. Mutation of human molybdenum cofactor sulfurase gene is responsible for classical xanthinuria type II. *Biochem Biophys Res Commun* **282,** 1194–1200 (2001).
124. 11306093: Aoki, S., Ishikura, S., Asada, Y., Usami, N. & Hara, A. Identity of dimeric dihydrodiol dehydrogenase as NADP(+)-dependent D-xylose dehydrogenase in pig liver. *Chem Biol Interact* **130–132,** 775–784 (2001).
125. 11342103: Charbonneau, A. & The, V. L. Genomic organization of a human 5beta-reductase and its pseudogene and substrate selectivity of the expressed enzyme. *Biochim Biophys Acta* **1517,** 228–235 (2001).
126. 11389701: de Graaf, M. *et al.* Cloning and characterization of human liver cytosolic beta-glycosidase. *Biochem J* **356,** 907–910 (2001).
127. 11401432: Yan, W. *et al.* Cloning and characterization of a human beta,beta-carotene-15,15'-dioxygenase that is highly expressed in the retinal pigment epithelium. *Genomics* **72,** 193–202 (2001).

128. 11737202: Traving, C., Bruse, P., Wächter, A. & Schauer, R. The sialate-pyruvate lyase from pig kidney. Elucidation of the primary structure and expression of recombinant enzyme activity. *Eur J Biochem* **268,** 6473–6486 (2001).
129. 11827462: Kim, D. K. *et al.* The human T-type amino acid transporter-1: characterization, gene organization, and chromosomal location. *Genomics* **79,** 95–103 (2002).
130. 11937514: Ternes, P., Franke, S., Zähringer, U., Sperling, P. & Heinz, E. Identification and characterization of a sphingolipid delta 4-desaturase family. *J Biol Chem* **277,** 25512–25518 (2002).
131. 11997390: Sontag, T. J. & Parker, R. S. Cytochrome P450 omega-hydroxylase pathway of tocopherol catabolism. Novel mechanism of regulation of vitamin E status. *J Biol Chem* **277,** 25290–25296 (2002).
132. 12023972: Farrar, C., & Clarke, S. Altered levels of S-adenosylmethionine and S-adenosylhomocysteine in the brains of L-isoaspartyl (D-Aspartyl) O-methyltransferase-deficient mice. *J Biol Chem* **277**: 27856-63 (2002).
133. 12072962: Elmore, B. O., Bollinger, J. A. & Dooley, D. M. Human kidney diamine oxidase: heterologous expression, purification, and characterization. *J Biol Inorg Chem* **7,** 565–579 (2002).
134. 12089149: Enomoto, A. *et al.* Molecular identification of a novel carnitine transporter specific to human testis. Insights into the mechanism of carnitine recognition. *J Biol Chem* **277,** 36262–36271 (2002).
135. 12093894: Pullinger, C. R. *et al.* Human cholesterol 7alpha-hydroxylase (CYP7A1) deficiency has a hypercholesterolemic phenotype. *J Clin Invest* **110,** 109–117 (2002).
136. 12105227: Venkataraman, K. *et al.* Upstream of growth and differentiation factor 1 (uog1), a mammalian homolog of the yeast longevity assurance gene 1 (LAG1), regulates N-stearoyl-sphinganine (C18-(dihydro)ceramide) synthesis in a fumonisin B1-independent manner in mammalian cells. *J Biol Chem* **277,** 35642–35649 (2002).
137. 12359132: Nguyen, T. V. *et al.* Identification of isobutyryl-CoA dehydrogenase and its deficiency in humans. *Mol Genet Metab* **77,** 68–79 (2002).
138. 12371743: Leonard, A. E. *et al.* Identification and expression of mammalian long-chain PUFA elongation enzymes. *Lipids* **37,** 733–740 (2002).
139. 12569161: Jin, W., Millar, J. S., Broedl, U., Glick, J. M. & Rader, D. J. Inhibition of endothelial lipase causes increased HDL cholesterol levels in vivo. *J Clin Invest* **111,** 357–362 (2003).
140. 12606581: Zhang, Y. *et al.* HDAC-6 interacts with and deacetylates tubulin and microtubules in vivo. *EMBO J* **22,** 1168–1179 (2003).
141. 12660232: Wu, T., Yankovskaya, V. & McIntire, W. S. Cloning, sequencing, and heterologous expression of the murine peroxisomal flavoprotein, N1-acetylated polyamine oxidase. *J Biol Chem* **278,** 20514–20525 (2003).
142. 12694300: Rutkowski, B. *et al.* N-methyl-2-pyridone-5-carboxamide: a novel uremic toxin? *Kidney Int Suppl* S19-21 (2003). doi:10.1046/j.1523-1755.63.s84.36.x
143. 12730697: Abifadel, M. *et al.* Mutations in PCSK9 cause autosomal dominant hypercholesterolemia. *Nat Genet* **34,** 154–156 (2003).
144. 12912983: Riebeling, C., Allegood, J. C., Wang, E., Merrill, A. H. & Futerman, A. H. Two mammalian longevity assurance gene (LAG1) family members, trh1 and trh4, regulate dihydroceramide synthesis using different fatty acyl-CoA donors. *J Biol Chem* **278,** 43452–43459 (2003).
145. 12917409: Wang, N. *et al.* ATP-binding cassette transporter A7 (ABCA7) binds apolipoprotein A-I and mediates cellular phospholipid but not cholesterol efflux. *J Biol Chem* **278,** 42906–42912 (2003).
146. 13018112: Hall, D. A. Histidine alpha-deaminase and the production of urocanic acid in the mammal. *Biochem J* **51,** 499–504 (1952).
147. 13032082: Knox, W. E. The relation of liver kynureninase to tryptophan metabolism in pyridoxine deficiency. *Biochem J* **53,** 379–385 (1953).
148. 13457352: Rendina, G. & Coon, M. J. Enzymatic hydrolysis of the coenzyme a thiol esters of beta-hydroxypropionic and beta-hydroxyisobutyric acids. *J Biol Chem* **225,** 523–534 (1957).
149. 13538975: Caravaca, J. & Grisolia, S. Enzymatic decarbamylation of carbamyl beta-alanine and carbamyl beta-aminoisobutyric acid. *J Biol Chem* **231,** 357–365 (1958).

150. 13575440: Axelrod, J. & Tomchick, R. Enzymatic O-methylation of epinephrine and other catechols. *J Biol Chem* **233,** 702–705 (1958).
151. 13672973: Tabor, H. & Wyngarden, L. The enzymatic formation of formiminotetrahydrofolic acid, 5,10-methenyltetrahydrofolic acid, and 10-formyltetrahydrofolic acid in the metabolism of formiminoglutamic acid. *J Biol Chem* **234,** 1830–1846 (1959).
152. 13716069: Hoskins, D. D. & Mackenzie, C. G. Solubilization and electron transfer flavoprtein requirement of mitochondrial sarcosine dehydrogenase and dimethylglycine dehydrogenase. *J Biol Chem* **236,** 177–183 (1961).
153. 13752080: Kaziro, Y., Ochoa, S., Warner, R. C. & Chen, J. Y. Metabolism of propionic acid in animal tissues. VIII. Crystalline propionyl carboxylase. *J Biol Chem* **236,** 1917–1923 (1961).
154. 13758723: Lane, M. D., Halenz, D. R., Kosow, D. P. & Hegre, C. S. Further studies on mitochondrial propionyl carboxylase. *J Biol Chem* **235,** 3082–3086 (1960).
155. 14081922: Kizer, D. E., Cox, B., Lovig, C. A. & Francodeestrugo, S. ADENYLIC ACID DEAMINASE OF RAT LIVER. *J Biol Chem* **238,** 3048–3052 (1963).
156. 14216443: Nagatsu, T., Levitt, M. & Udenfriend, S. TYROSINE HYDROXYLASE. The initial step in norepinephrine biosynthesis. *J Biol Chem* **239,** 2910–2917 (1964).
157. 14253475: Friedman, S. & Kaufman, S. 3,4-dihydroxyphenylethylamine beta-hydroxylase: a copper protein. *J Biol Chem* **240,** PC552-554 (1965).
158. 14504269: Graf, G. A. *et al.* ABCG5 and ABCG8 are obligate heterodimers for protein trafficking and biliary cholesterol excretion. *J Biol Chem* **278,** 48275–48282 (2003).
159. 14569421: Burk, O. & Wojnowski, L. Cytochrome P450 3A and their regulation. *Naunyn Schmiedebergs Arch Pharmacol* **369,** 105–124 (2004).
160. 14656720: Pushkin, A. *et al.* Structural characterization, tissue distribution, and functional expression of murine aminoacylase III. *Am J Physiol Cell Physiol* **286,** C848-856 (2004).
161. 14674884: Agrimi, G. *et al.* Identification of the human mitochondrial S-adenosylmethionine transporter: bacterial expression, reconstitution, functional characterization and tissue distribution. *Biochem J* **379,** 183–190 (2004).
162. 14794728: Mehler, A. H. & Knox, W. E. The conversion of tryptophan to kynurenine in liver. II. The enzymatic hydrolysis of formylkynurenine. *J Biol Chem* **187,** 431–438 (1950).
163. 15026176: Penning, T. M., Jin, Y., Steckelbroeck, S., Lanisnik Rizner, T. & Lewis, M. Structure-function of human 3 alpha-hydroxysteroid dehydrogenases: genes and proteins. *Mol Cell Endocrinol* **215,** 63–72 (2004).
164. 15044460: Bröer, A. *et al.* Molecular cloning of mouse amino acid transport system B0, a neutral amino acid transporter related to Hartnup disorder. *J Biol Chem* **279,** 24467–24476 (2004).
165. 15283699: Coleman, C. S., Stanley, B. A., Jones, A. D. & Pegg, A. E. Spermidine/spermine-N1-acetyltransferase-2 (SSAT2) acetylates thialysine and is not involved in polyamine metabolism. *Biochem J* **384,** 139–148 (2004).
166. 15361070: Molinaro, G. *et al.* Human recombinant membrane-bound aminopeptidase P: production of a soluble form and characterization using novel, internally quenched fluorescent substrates. *Biochem J* **385,** 389–397 (2005).
167. 15561973: Burckhardt, B. C., Lorenz, J., Kobbe, C. & Burckhardt, G. Substrate specificity of the human renal sodium dicarboxylate cotransporter, hNaDC-3, under voltage-clamp conditions. *Am J Physiol Renal Physiol* **288,** F792-799 (2005).
168. 15606768: Han, Q., Li, J. & Li, J. pH dependence, substrate specificity and inhibition of human kynurenine aminotransferase I. *Eur J Biochem* **271,** 4804–4814 (2004).
169. 15632147: Takanaga, H., Mackenzie, B., Suzuki, Y. & Hediger, M. A. Identification of mammalian proline transporter SIT1 (SLC6A20) with characteristics of classical system imino. *J Biol Chem* **280,** 8974–8984 (2005).
170. 15655246: Tsuboi, K. *et al.* Molecular characterization of N-acylethanolamine-hydrolyzing acid amidase, a novel member of the choloylglycine hydrolase family with structural and functional similarity to acid ceramidase. *J Biol Chem* **280,** 11082–11092 (2005).
171. 15702409: Matsuo, M., Tasaki, R., Kodama, H. & Hamasaki, Y. Screening for Menkes disease using the urine HVA/VMA ratio. *J Inherit Metab Dis* **28,** 89–93 (2005).
172. 15804236: Böhmer, C. *et al.* Characterization of mouse amino acid transporter B0AT1 (slc6a19). *Biochem J* **389,** 745–751 (2005).

173. 15809331: Ishikura, S., Usami, N., Araki, M. & Hara, A. Structural and functional characterization of rabbit and human L-gulonate 3-dehydrogenase. *J Biochem* **137,** 303–314 (2005).
174. 15907797: Wang, J. *et al.* Characterization of HSCD5, a novel human stearoyl-CoA desaturase unique to primates. *Biochem Biophys Res Commun* **332,** 735–742 (2005).
175. 15968458: Amici, A., Ciccioli, K., Naponelli, V., Raffaelli, N. & Magni, G. Evidence for essential catalytic determinants for human erythrocyte pyrimidine 5'-nucleotidase. *Cell Mol Life Sci* **62,** 1613–1620 (2005).
176. 15980104: Kimura, M. *et al.* Cyp2a6 is a principal enzyme involved in hydroxylation of 1,7-dimethylxanthine, a main caffeine metabolite, in humans. *Drug Metab Dispos* **33,** 1361–1366 (2005).
177. 16317684: Ballatori, N. *et al.* OSTalpha-OSTbeta: a major basolateral bile acid and steroid transporter in human intestinal, renal, and biliary epithelia. *Hepatology* **42,** 1270–1279 (2005).
178. 16399346: Court, M.H. Isoform-selective probe substrates for in vitro studies of human UDP-glucuronosyltransferases. *Methods Enzymol* **400**,104-16 (2005).
179. 16491085: Mills, P. B. *et al.* Mutations in antiquitin in individuals with pyridoxine-dependent seizures. *Nat Med* **12,** 307–309 (2006).
180. 16589713: Ichihara, A. & Greenberg, D. M. Pathway of serine formation from carbohydrate in rat liver. *Proc Natl Acad Sci U S A* **41,** 605–609 (1955).
181. 16807375: Shin, M., Kim, I., Inoue, Y., Kimura, S. & Gonzalez, F. J. Regulation of mouse hepatic alpha-amino-beta-carboxymuconate-epsilon-semialdehyde decarboxylase, a key enzyme in the tryptophan-nicotinamide adenine dinucleotide pathway, by hepatocyte nuclear factor 4alpha and peroxisome proliferator-activated receptor alpha. *Mol Pharmacol* **70,** 1281–1290 (2006).
182. 16842543: Ha, E. *et al.* Melatonin stimulates glucose transport via insulin receptor substrate-1/phosphatidylinositol 3-kinase pathway in C2C12 murine skeletal muscle cells. *J Pineal Res* **41,** 67–72 (2006).
183. 16874462: Hu, C. A. *et al.* Overexpression of proline oxidase induces proline-dependent and mitochondria-mediated apoptosis. *Mol Cell Biochem* **295,** 85–92 (2007).
184. 16940157: Hunt, M. C., Rautanen, A., Westin, M. A. K., Svensson, L. T. & Alexson, S. E. H. Analysis of the mouse and human acyl-CoA thioesterase (ACOT) gene clusters shows that convergent, functional evolution results in a reduced number of human peroxisomal ACOTs. *FASEB J* **20,** 1855–1864 (2006).
185. 16992869: Plimmer, R. H. On the presence of lactase in the intestines of animals and on the adaptation of the intestine to lactose. *J Physiol* **35,** 20–31 (1906).
186. 17015445: Wei, B. Q., Mikkelsen, T. S., McKinney, M. K., Lander, E. S. & Cravatt, B. F. A second fatty acid amide hydrolase with variable distribution among placental mammals. *J Biol Chem* **281,** 36569–36578 (2006).
187. 17023427: Hornemann, T., Richard, S., Rütti, M. F., Wei, Y. & von Eckardstein, A. Cloning and initial characterization of a new subunit for mammalian serine-palmitoyltransferase. *J Biol Chem* **281,** 37275–37281 (2006).
188. 17393504: Shin, H. J. *et al.* Novel liver-specific organic anion transporter OAT7 that operates the exchange of sulfate conjugates for short chain fatty acid butyrate. *Hepatology* **45,** 1046–1055 (2007).
189. 17412732: Gempel, K. *et al.* The myopathic form of coenzyme Q10 deficiency is caused by mutations in the electron-transferring-flavoprotein dehydrogenase (ETFDH) gene. *Brain* **130,** 2037–2044 (2007).
190. 17707131: Yamashita, A. *et al.* Topology of acyltransferase motifs and substrate specificity and accessibility in 1-acyl-sn-glycero-3-phosphate acyltransferase 1. *Biochim Biophys Acta* **1771,** 1202–1215 (2007).
191. 17896864: Kaper, T. *et al.* Nanosensor detection of an immunoregulatory tryptophan influx/kynurenine efflux cycle. *PLoS Biol* **5,** e257 (2007).
192. 18088226: Dungan, K. M. 1,5-anhydroglucitol (GlycoMark) as a marker of short-term glycemic control and glycemic excursions. *Expert Rev Mol Diagn* **8,** 9–19 (2008).
193. 18094042: Lee, H.-C. *et al.* Caenorhabditis elegans mboa-7, a member of the MBOAT family, is required for selective incorporation of polyunsaturated fatty acids into phosphatidylinositol. *Mol Biol Cell* **19,** 1174–1184 (2008).

194. 18222180: Lindner, H. A., Täfler-Naumann, M. & Röhm, K.-H. N-acetylamino acid utilization by kidney aminoacylase-1. *Biochimie* **90,** 773–780 (2008).
195. 18230605: Szegedi, S. S., Castro, C. C., Koutmos, M. & Garrow, T. A. Betaine-homocysteine S-methyltransferase-2 is an S-methylmethionine-homocysteine methyltransferase. *J Biol Chem* **283,** 8939–8945 (2008).
196. 18327257: Vitart, V. *et al.* SLC2A9 is a newly identified urate transporter influencing serum urate concentration, urate excretion and gout. *Nat Genet* **40,** 437–442 (2008).
197. 18632736: Yonezawa, A., Masuda, S., Katsura, T. & Inui, K. Identification and functional characterization of a novel human and rat riboflavin transporter, RFT1. *Am J Physiol Cell Physiol* **295,** C632-641 (2008).
198. 18775983: Novick, R. M. & Elfarra, A. A. Purification and characterization of flavin-containing monooxygenase isoform 3 from rat kidney microsomes. *Drug Metab Dispos* **36,** 2468–2474 (2008).
199. 18902391: Kazenko, A. & Laskowski, M. On the specificity of chicken pancreas conjugase (gamma-glutamic acid carboxypeptidase). *J Biol Chem* **173,** 217–221 (1948).
200. 18941301: Kikuchi, G., Motokawa, Y., Yoshida, T. & Hiraga, K. Glycine cleavage system: reaction mechanism, physiological significance, and hyperglycinemia. *Proc Jpn Acad Ser B Phys Biol Sci* **84,** 246–263 (2008).
201. 18981171: Mackenzie, P. I. *et al.* Identification of UDP glycosyltransferase 3A1 as a UDP N-acetylglucosaminyltransferase. *J Biol Chem* **283,** 36205–36210 (2008).
202. 19339287: Eminoglu, F. T. *et al.* 3-Methylcrotonyl-CoA carboxylase deficiency: phenotypic variability in a family. *J Child Neurol* **24,** 478–481 (2009).
203. 19411760: Lu, G. *et al.* Protein phosphatase 2Cm is a critical regulator of branched-chain amino acid catabolism in mice and cultured cells. *J Clin Invest* **119,** 1678–1687 (2009).
204. 19453107: Zhao, H., Martin, B. M., Bisoffi, M. & Dunaway-Mariano, D. The Akt C-terminal modulator protein is an acyl-CoA thioesterase of the Hotdog-Fold family. *Biochemistry* **48,** 5507–5509 (2009).
205. 19506252: Woodward, O. M. *et al.* Identification of a urate transporter, ABCG2, with a common functional polymorphism causing gout. *Proc Natl Acad Sci U S A* **106,** 10338–10342 (2009).
206. 19595734: Krasnikov, B. F. *et al.* Identification of the putative tumor suppressor Nit2 as omega-amidase, an enzyme metabolically linked to glutamine and asparagine transamination. *Biochimie* **91,** 1072–1080 (2009).
207. 19679820: Fujita, M. *et al.* Hepatic uptake of gamma-butyrobetaine, a precursor of carnitine biosynthesis, in rats. *Am J Physiol Gastrointest Liver Physiol* **297,** G681-686 (2009).
208. 20285042: Kalckar, H. M. The enzymatic synthesis of purine ribosides. *J Biol Chem* **167,** 477–486 (1947).
209. 20335586: Magen, D. *et al.* A loss-of-function mutation in NaPi-IIa and renal Fanconi's syndrome. *N Engl J Med* **362,** 1102–1109 (2010).
210. 21515882: Wu, L.-C. *et al.* Purification, identification, and cloning of lysoplasmalogenase, the enzyme that catalyzes hydrolysis of the vinyl ether bond of lysoplasmalogen. *J Biol Chem* **286,** 24916–24930 (2011).
211. 21733844: Öberg, F. *et al.* Glycosylation increases the thermostability of human aquaporin 10 protein. *J Biol Chem* **286,** 31915–31923 (2011).
212. 21846720: Witkowski, A., Thweatt, J. & Smith, S. Mammalian ACSF3 protein is a malonyl-CoA synthetase that supplies the chain extender units for mitochondrial fatty acid synthesis. *J Biol Chem* **286,** 33729–33736 (2011).
213. 21886157: Suhre, K. *et al.* Human metabolic individuality in biomedical and pharmaceutical research. *Nature* **477,** 54–60 (2011).
214. 21908619: Collard, F., Vertommen, D., Constantinescu, S., Buts, L. & Van Schaftingen, E. Molecular identification of β-citrylglutamate hydrolase as glutamate carboxypeptidase 3. *J Biol Chem* **286,** 38220–38230 (2011).
215. 21926997: Long, J. Z. *et al.* Metabolomics annotates ABHD3 as a physiologic regulator of medium-chain phospholipids. *Nat Chem Biol* **7,** 763–765 (2011).
216. 22016388: Linster, C. L. *et al.* Ethylmalonyl-CoA decarboxylase, a new enzyme involved in metabolite proofreading. *J Biol Chem* **286,** 42992–43003 (2011).
217. 22063269: Mattijssen, F. & Kersten, S. Regulation of triglyceride metabolism by Angiopoietin-like proteins. *Biochim Biophys Acta* **1821,** 782–789 (2012).

218. 22241472: Veiga-da-Cunha, M., Hadi, F., Balligand, T., Stroobant, V. & Van Schaftingen, E. Molecular identification of hydroxylysine kinase and of ammoniophospholyases acting on 5-phosphohydroxy-L-lysine and phosphoethanolamine. *J Biol Chem* **287,** 7246–7255 (2012).
219. 22427816: Ehrlund, A. *et al.* Knockdown of SF-1 and RNF31 affects components of steroidogenesis, TGFβ, and Wnt/β-catenin signaling in adrenocortical carcinoma cells. *PLoS One* **7,** e32080 (2012).
220. 22586271: Zhuravleva, E. *et al.* Acyl coenzyme A thioesterase Them5/Acot15 is involved in cardiolipin remodeling and fatty liver development. *Mol Cell Biol* **32,** 2685–2697 (2012).
221. 22952014: Tamai, I. Pharmacological and pathophysiological roles of carnitine/organic cation transporters (OCTNs: SLC22A4, SLC22A5 and Slc22a21). *Biopharm Drug Dispos* **34**:29-44 (2013).
222. 23010440: Davids, M., Ndika, J. D. T., Salomons, G. S., Blom, H. J. & Teerlink, T. Promiscuous activity of arginine:glycine amidinotransferase is responsible for the synthesis of the novel cardiovascular risk factor homoarginine. *FEBS Lett* **586,** 3653–3657 (2012).
223. 23024808: De Ingeniis, J. *et al.* Functional specialization in proline biosynthesis of melanoma. *PLoS One* **7,** e45190 (2012).
224. 23038267: Liu, P. *et al.* Role of glutamate decarboxylase-like protein 1 (GADL1) in taurine biosynthesis. *J Biol Chem* **287,** 40898–40906 (2012).
225. 23141293: Danhauser, K. *et al.* DHTKD1 mutations cause 2-aminoadipic and 2-oxoadipic aciduria. *Am J Hum Genet* **91,** 1082–1087 (2012).
226. 23266187: Palmieri, F. The mitochondrial transporter family SLC25: identification, properties and physiopathology. *Mol Aspects Med* **34,** 465–484 (2013).
227. 23506882: Bürzle, M. *et al.* The sodium-dependent ascorbic acid transporter family SLC23. *Mol Aspects Med* **34,** 436–454 (2013).
228. 23798576: Karamitri, A., Renault, N., Clement, N., Guillaume, J.-L. & Jockers, R. Minireview: Toward the establishment of a link between melatonin and glucose homeostasis: association of melatonin MT2 receptor variants with type 2 diabetes. *Mol Endocrinol* **27,** 1217–1233 (2013).
229. 23863933: Simanshu, D. K. *et al.* Non-vesicular trafficking by a ceramide-1-phosphate transfer protein regulates eicosanoids. *Nature* **500,** 463–467 (2013).
230. 24121108: Yamada, S. & Arikawa, S. An ectotherm homologue of human predicted gene NAT16 encodes histidine N-acetyltransferase responsible for Nα-acetylhistidine synthesis. *Biochim Biophys Acta* **1840,** 434–442 (2014).
231. 24573086: Ghezzi, C. *et al.* Fingerprints of hSGLT5 sugar and cation selectivity. *Am J Physiol Cell Physiol* **306,** C864-870 (2014).
232. 24586186: Rueedi, R. *et al.* Genome-wide association study of metabolic traits reveals novel gene-metabolite-disease links. *PLoS Genet* **10,** e1004132 (2014).
233. 24652292: Porcelli, V., Fiermonte, G., Longo, A. & Palmieri, F. The human gene SLC25A29, of solute carrier family 25, encodes a mitochondrial transporter of basic amino acids. *J Biol Chem* **289,** 13374–13384 (2014).
234. 24697329: Wichelecki, D. J. *et al.* Enzymatic and structural characterization of rTSγ provides insights into the function of rTSβ. *Biochemistry* **53,** 2732–2738 (2014).
235. 24768817: Nomme, J., Su, Y. & Lavie, A. Elucidation of the specific function of the conserved threonine triad responsible for human L-asparaginase autocleavage and substrate hydrolysis. *J Mol Biol* **426,** 2471–2485 (2014).
236. 24847004: Houten, S. M. *et al.* Mitochondrial NADP(H) deficiency due to a mutation in NADK2 causes dienoyl-CoA reductase deficiency with hyperlysinemia. *Hum Mol Genet* **23,** 5009–5016 (2014).
237. 24891507: Veiga-da-Cunha, M., Chevalier, N., Stroobant, V., Vertommen, D. & Van Schaftingen, E. Metabolite proofreading in carnosine and homocarnosine synthesis: molecular identification of PM20D2 as β-alanyl-lysine dipeptidase. *J Biol Chem* **289,** 19726–19736 (2014).
238. 24927523: Mahdessian, H. *et al.* TM6SF2 is a regulator of liver fat metabolism influencing triglyceride secretion and hepatic lipid droplet content. *Proc Natl Acad Sci U S A* **111,** 8913–8918 (2014).
239. 25231977: Pinto, J. T. *et al.* Kynurenine aminotransferase III and glutamine transaminase L are identical enzymes that have cysteine S-conjugate β-lyase activity and can transaminate L-selenomethionine. *J Biol Chem* **289,** 30950–30961 (2014).

240. 25760036: Ellis, J. M., Bowman, C. E. & Wolfgang, M. J. Metabolic and tissue-specific regulation of acyl-CoA metabolism. *PLoS One* **10,** e0116587 (2015).
241. 25947375: Naito, T. *et al.* Phospholipid Flippase ATP10A Translocates Phosphatidylcholine and Is Involved in Plasma Membrane Dynamics. *J Biol Chem* **290,** 15004–15017 (2015).
242. 26014429: Heemskerk, M. M., van Harmelen, V. J. A., van Dijk, K. W. & van Klinken, J. B. Reanalysis of mGWAS results and in vitro validation show that lactate dehydrogenase interacts with branched-chain amino acid metabolism. *Eur J Hum Genet* **24,** 142–145 (2016).
243. 26234207: Mattjus, P. Specificity of the mammalian glycolipid transfer proteins. *Chem Phys Lipids* **194,** 72–78 (2016).
244. 26517927: Bauer, R. C., Yenilmez, B. O. & Rader, D. J. Tribbles-1: a novel regulator of hepatic lipid metabolism in humans. *Biochem Soc Trans* **43,** 1079–1084 (2015).
245. 27180734: Deol, R. & Josephy, P. D. Acetylation of aromatic cysteine conjugates by recombinant human N-acetyltransferase 8. *Xenobiotica* **47,** 202–207 (2017).
246. 27288731: Halwachs, S., Schäfer, I., Kneuer, C., Seibel, P. & Honscha, W. Assessment of ABCG2-mediated transport of pesticides across the rabbit placenta barrier using a novel MDCKII in vitro model. *Toxicol Appl Pharmacol* **305,** 66–74 (2016).
247. 28257906: Holmes, R. S. Comparative and evolutionary studies of mammalian arylsulfatase and sterylsulfatase genes and proteins encoded on the X-chromosome. *Comput Biol Chem* **68,** 71–77 (2017).
248. 28465440: Toomey, M. B. *et al.* High-density lipoprotein receptor SCARB1 is required for carotenoid coloration in birds. *Proc Natl Acad Sci U S A* **114,** 5219–5224 (2017).
249. 28516954: Hai, Y., Shinsky, S. A., Porter, N. J. & Christianson, D. W. Histone deacetylase 10 structure and molecular function as a polyamine deacetylase. *Nat Commun* **8,** 15368 (2017).
250. 28642719: Eriksson, O., Lalowski, M. & Lindholm, D. Commentary: LACTB is a tumour suppressor that modulates lipid metabolism and cell state. *Front Physiol* **8,** 396 (2017).
251. 28942964: Kim, H. I. *et al.* Fine Mapping and Functional Analysis Reveal a Role of SLC22A1 in Acylcarnitine Transport. *Am J Hum Genet* **101,** 489–502 (2017).
252. 29578721: Zhang, Q., Ford, L. A., Evans, A. M. & Toal, D. R. Identification of an Endogenous Organosulfur Metabolite by Interpretation of Mass Spectrometric Data. *Org Lett* **20,** 2100–2103 (2018).
253. 30913229: Pirim, D. *et al.* Apolipoprotein E-C1-C4-C2 gene cluster region and inter-individual variation in plasma lipoprotein levels: a comprehensive genetic association study in two ethnic groups. *PLoS One* **14,** e0214060 (2019).
254. 31764986: Laufs, U., Parhofer, K. G., Ginsberg, H. N. & Hegele, R. A. Clinical review on triglycerides. *Eur Heart J* **41,** 99-109c (2020).
255. 33415501: Di, L., Balesano, A., Jordan, S. & Shi, S. M. The Role of Alcohol Dehydrogenase in Drug Metabolism: Beyond Ethanol Oxidation. *AAPS J* **23,** 20 (2021).