

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

<u>NAT1 Allele (Haplotype)^a</u>	<u>Nucleotide Change(s) and rs Identifier(s)</u>	<u>Amino Acid Change(s)</u>	<u>Phenotype^b</u>	<u>References</u>
<i>NAT1*4</i>	Reference	Reference	Reference	2, 79-86
<i>NAT1*3</i>	1095C>A (rs15561)			5, 12, 100
<i>NAT1*5</i>	350,351G>C (rs72554606) 497-499G>C (rs72554608) 884A>G (rs55793712) Δ ⁹⁷⁶ (rs72554612) Δ ¹¹⁰⁵ (rs72554613)	R117T R166T; E167Q		7
<i>NAT1*10</i>	1088T>A (rs1057126) 1095C>A (rs15561)			2,9,10, 12,13, 59,79,80,82, 87
<i>NAT1*11A</i>	-344C>T (rs4986988) -40A>T (rs4986989) 445G>A (rs4987076) 459G>A (rs4986990) 640T>G (rs4986783) Δ 9 between 1065-1090 1095C>A (rs15561)	V149I T153T (synonymous) S214A		8,12,86, 87
<i>NAT1*11B</i>	-344C>T (rs4986988) -40A>T (rs4986989) 445G>A (rs4987076) 459G>A (rs4986990) 640T>G (rs4986783) Δ 9 between 1065-1090	V149I T153T (synonymous) S214A		60, 86, 87
<i>NAT1*11C</i>	-344C>T (rs4986988) -40A>T (rs4986989) 459G>A (rs4986990) 640T>G (rs4986783) Δ 9 between 1065-1090 1095C>A (rs15561)	T153T (synonymous) S214A		64
<i>NAT1*14A</i>	560G>A (rs4986782) 1088T>A (rs1057126) 1095C>A (rs15561)	R187Q	Lower than <i>NAT1*4</i> “Slow”	9,10, 87

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

<i>NAT1*14B</i>	560G>A (rs4986782)	R187Q	Lower than <i>NAT1*4</i> “Slow”	10,11, 79, 81-86
<i>NAT1*15</i>	559C>T (rs5030839)	R187Stop	Lower than <i>NAT1*4</i> “Slow”	9,11, 79, 81- 86
<i>NAT1*16</i>	[AAA] immediately after 1091 1095C>A (rs15561)			12
<i>NAT1*17</i>	190C>T (rs56379106)	R64W	Lower than <i>NAT1*4</i> “Slow”	13,14, 79, 81-86
<i>NAT1*18A</i>	Δ 3 between 1065-1087 (rs4646271) 1088T>A (rs1057126) 1095C>A (rs15561)			15,59, 66
<i>NAT1*18B</i>	Δ3 between 1065-1090 (rs4646271)			16,59, 66
<i>NAT1*19A</i>	97C>T (rs56318881)	R33Stop	Truncated protein/ no enzyme activity	14, 79, 81-86
<i>NAT1*19B</i>	97C>T (rs56318881) 190C>T (rs56379106)	R33Stop R64W	Truncated protein/ no enzyme activity	101
<i>NAT1*20</i>	402T>C	P134P (synonymous)	Equivalent to <i>NAT1*4</i>	14, 79, 81-86
<i>NAT1*21</i>	613A>G (rs72554609)	M205V	Equivalent to <i>NAT1*4</i>	14, 79 81-86
<i>NAT1*22</i>	752A>T (rs56172717)	D251V	Lower than <i>NAT1*4</i> “Slow”	14, 79 81-87
<i>NAT1*23</i>	777T>C (rs4986991)	S259S (synonymous)	Equivalent to <i>NAT1*4</i>	14, 79 81-86

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

<i>NAT1*24</i>	781G>A (rs72554610)	E261K	Equivalent to <i>NAT1*4</i>	14, 79 81-86
<i>NAT1*25</i>	787A>G (rs72554611)	I263V	Equivalent to <i>NAT1*4</i>	14, 79 81-86
<i>NAT1*26A</i>	[TAA] insertion between 1065 and 1090 1095C>A (rs15561)			17
<i>NAT1*26B</i>	[TAA] insertion between 1065 and 1090			18
<i>NAT1*27</i>	21T>G (rs4986992) 777T>C (rs4986991)	L7L (synonymous) S259S (synonymous)	Equivalent to <i>NAT1*4</i>	19, 79 81-86
<i>NAT1*28</i>	[TAATAA] deletion between 1065 - 1090			20,61
<i>NAT1*29</i>	1088T>A (rs1057126) 1095C>A (rs15561) Δ¹⁰²⁵			21,61
<i>NAT1*30</i>	445G>A (rs4987076)	V149I		101

Notes:

- ^aHuman *NAT1* alleles should be written in upper case and italicized. Protein products of the alleles are also upper case but not italicized and the asterisk is omitted. For example, the allele *NAT1*4* encodes the protein NAT1 4.
- ^aReference gene sequence published in [Genbank Accession Number X17059](#)
- ^a*NAT1*4* has historically been designated "wildtype". Since it is the most common occurring alleles in some but not all ethnic groups the designation of "wildtype" allele is somewhat arbitrary and is dependent upon the ethnicity of the population studied.
- ^bPhenotype assignments reflect most current research but are not necessarily consistent across all studies. As recently reviewed (88, 89), the functional effects of genetic polymorphisms in the 3'UTR of *NAT1* are poorly understood. The phenotype of *NAT1*10* has been particularly inconsistent as multiple studies report an elevated activity both *in vivo* and *in vitro*, whereas multiple studies report that the activity is not elevated *in vivo* nor *in vitro*. Phenotypes may vary with organ/tissue and may be

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

dependent upon other endogenous and environmental factors. Evidence exists for heterogeneity within the “slow” acetylator phenotype.

- Although additional SNPs have been identified outside the open reading frame, they will not be named until a functional effect is observed. SNPs should be identified by designating "A" of the ATG translation initiation codon as number 1. SNPs upstream of this site are designated by negative numbers and SNPs downstream of this site are designated by positive numbers.

References

1. Deguchi, T. Sequences and expression of alleles of polymorphic arylamine N-acetyltransferase of human liver. *J. Biol. Chem.* 267: 18140-18147, 1992.
2. Vatsis, K.P., and Weber, W.W. Structural heterogeneity of Caucasian N-acetyltransferase at the NAT1 gene locus. *Arch. Biochem. Biophys.* 301: 71-76, 1993.
3. Blum, M., Demierre, A., Grant, D.M., Heim, M., and Meyer, U.A. Molecular mechanism of slow acetylation of drugs and carcinogens in humans. *Proc. Natl. Acad. Sci. USA* 88: 5237-5241, 1991.
4. Vatsis, K.P., Martell, K.J., and Weber, W.W. Diverse point mutations in the human gene for polymorphic N-acetyltransferase. *Proc. Natl. Acad. Sci. USA* 88: 6333-6337, 1991.
5. Blum, M., Grant, D.M., McBride, W., Heim, M., and Meyer, U.A. Human arylamine N-acetyltransferase genes: isolation, chromosomal localization, and functional expression. *DNA Cell Biol.* 9: 193-203, 1990.
6. Ebisawa, T., and Deguchi, T. Structure and restriction fragment length polymorphism of genes for human liver arylamine N-acetyltransferases. *Biochem. Biophys. Res. Commun.* 177: 1252-1257, 1991.
7. Ohsako, S., and Deguchi, T. Cloning and expression of cDNAs for polymorphic and monomorphic arylamine N-acetyltransferases from human liver. *J. Biol. Chem.* 265: 4630-4634, 1990.
8. Doll, M.A., Jiang, W., Deitz, A.C., Rustan, T.D., and Hein, D.W. Identification of a novel allele at the human NAT1 acetyltransferase locus. *Biochem. Biophys. Res. Comm.* 233: 584-591, 1997.
9. Hughes, N.C., Janezic, S.A., McQueen, K.L., Jewett, M.A.S., Castranio, T., Bell, D.A., and Grant, D.M. Identification and characterization of variant alleles of human acetyltransferase NAT1 with defective function using p-aminosalicylate as an in-vivo and in-vitro probe. *Pharmacogenetics* 8: 55-66, 1998.
10. Payton, M.A., and Sim, E. Genotyping human arylamine N-acetyltransferase Type 1 (NAT1): The identification of two novel allelic variants. *Biochem. Pharmacol.* 55: 361-366, 1998.
11. Hubbard, A., Moyes, C., Wyllie, A.H., Smith, C.A.D., and Harrison, D.J. N-acetyltransferase 1: two polymorphisms in coding sequence identified in colorectal cancer patients. *Br. J. Cancer* 77: 913-916, 1998.
12. de Leon, J.H., Vatsis, K.P., and Weber, W.W. Characterization of naturally occurring and recombinant human N-acetyltransferase variants encoded by NAT1*. *Mol. Pharmacol.* 58: 288-299, 2000.

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

13. Butcher, N.J., Ilett, K.F., and Minchin, R. F. Functional polymorphism of the human arylamine N-acetyltransferase type 1 gene caused by C190T and G560A mutations. *Pharmacogenetics* 8: 67-72, 1998.
14. Lin, H.J., Probst-Hensch, N.M., Hughes, N.C., Sakamoto, G.T., Louie, A.D., Kau, I.H., Lin, B.K., Lee, D.B., Lin, J. Frankl, H.D., Lee, E.R., Hardy, S., Grant, D.M., and Haile, R.W. Variants of N-acetyltransferase NAT1 and a case-control study of colorectal adenomas. *Pharmacogenetics* 8: 269-281, 1998.
15. Deitz, A.C., Doll, M.A., Fretland, A.J., and Hein, D.W. Homo sapiens N-acetyltransferase NAT1 (allele NAT1*18A) gene, complete cds. *Genbank* AF032677, 1997.
16. Deitz, A.C., Doll, M.A., Fretland, A.J., and Hein, D.W. Homo sapiens N-acetyltransferase NAT1 (allele NAT1*18B) gene, complete cds. *Genbank* AF032678, 1997.
17. Deitz, A.C., Fretland, A.J., Leff, M.A., and Hein, D.W. Homo sapiens N-acetyltransferase-1 (NAT1) gene, NAT1*26A allele, complete cds. *Genbank* AF071552, 1998.
18. Deitz, A.C., Fretland, A.J., Leff, M.A., Doll, M.A., and Hein, D.W. Homo sapiens N-acetyltransferase-1 (NAT1) gene, NAT1*26B allele, complete cds. *Genbank* AF067408, 1998.
19. Smelt, V.A., Upton, A., Adjaye, J, Payton, M.A., Boukouvala, S., Johnson, N., Mardon, H.J., and Sim, E. Expression of arylamine N-acetyltransferases in pre-term placentas and in human pre-implantation embryos. *Hum. Mol. Gen.* 9:1101-1107, 2000.
20. Lo-Guidice, J.-M., Marez, D., Barat, F., Spire, C., Chevalier, D., and Broly, F. Human N-acetyltransferase 1 (NAT1) gene, NAT1*28 allele. *Genbank* AF082904, 1999.
21. Lo-Guidice, J.-M., Marez, D., Barat, F., Spire, C., Chevalier, D., and Broly, F. Human N-acetyltransferase 1 (NAT1) gene, NAT1*29 allele. *Genbank* AF082903, 1999.
22. Grant, D.M., Blum, M., Demierre, A., and Meyer, U.A. Nucleotide sequence of an intronless gene for a human arylamine N-acetyltransferase related to polymorphic drug acetylation. *Nucleic Acids Res.* 17: 3978, 1989.
23. Hickman, D., and Sim, E. N-Acetyltransferase polymorphism: Comparison of phenotype and genotype in humans. *Biochem. Pharmacol.* 42: 1007-1014, 1992.
24. Hickman, D., Risch, A., Camilleri, J.P., and Sim, E. Genotyping human polymorphic arylamine N-acetyltransferase: identification of new slow allotypic variants. *Pharmacogenetics* 2: 217-226, 1992.
25. Lin, J.J., Han, C-Y., Link B.K., and Hardy, S. Slow acetylator mutations in the human polymorphic N-acetyltransferase gene in 786 Asians, Blacks, Hispanics, and Whites: application to metabolic epidemiology. *Am. J. Human Genet.* 52: 827-834, 1993.
26. Cascorbi, I., Drakoulis, N., Brockmoller, J., Mauer, A. Sperling, K., and Roots, I. Arylamine N-acetyltransferase (NAT2) mutations and their allelic linkage in unrelated Caucasian individuals: correlation with phenotypic activity. *Am. J. Hum. Genet.* 57: 581-592, 1995.
27. Abe, M., Deguchi, T., and Suzuki T. The structure and characteristics of a fourth allele of polymorphic N-acetyltransferase gene found in the Japanese population. *Biochem. Biophys. Res. Comm.* 191: 811-816, 1993.
28. Ferguson, R.J, Doll, M.A., Rustan, T.D., Gray, K., and Hein, D.W. Cloning, expression, and functional characterization of two mutant (NAT2 191 and NAT2 341/803) and wild-

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

- type human polymorphic N-acetyltransferase (NAT2) alleles. *Drug Metab. Dispos.* 22: 371-376, 1994.
29. Martinez, C., Agundez, J.A.G., Olivera M., Martin, R., Ladero, J.M., and Benitez, J. Lung cancer and mutations at the polymorphic NAT2 gene locus. *Pharmacogenetics* 5: 207-214, 1995.
 30. Agundez, J.A.G., Olivera, M., Ladero, J.M., Lescure-Rodriguez, A., Ledesma, M.C., Diaz-Rubio, M. Meyer, U.A., and Benitez, J. Increased risk for hepatocellular carcinoma in NAT2-slow acetylators and CYP2D6-rapid metabolizers. *Pharmacogenetics* 6: 501-512, 1996.
 31. Agundez, J.A.G., Olivera, M., Martinez, C., Ladero, J.M., and Benitez, J. Identification and prevalence study of 17 allelic variants of the human NAT2 gene in a white population. *Pharmacogenetics* 6: 423-428, 1996.
 32. Leff, M.A., Fretland, A.J., Doll, M.A., and Hein, D.W. Novel human N-acetyltransferase 2 alleles that differ in mechanism for slow acetylator phenotype. *J. Biol. Chem.* 274: 34519-34522, 1999.
 33. Woolhouse, N.M., Qureshi, M.M., and Bayoumi, R.A. A new mutation C759T in the polymorphic N-acetyltransferase (NAT2) gene. *Pharmacogenetics* 7: 83-84, 1997.
 34. Agundez, J.A., Martinez, C., Olivera, M., Ledesma, M.C., Ladero, J.M., and Benitez, J. Molecular analysis of the arylamine N-acetyltransferase polymorphism in a Spanish population. *Clin. Pharmacol. Ther.* 56: 202-209, 1994.
 35. Cascorbi, I., Brockmoller, J., Bauer, S., Reum, T., and Roots, I. NAT2*12A (803A-G) codes for rapid arylamine N-acetylation in humans. *Pharmacogenetics* 6: 257-259, 1996.
 36. Bell, D.A., Taylor, J.A., Butler, M.A., Stephens, E.A., Wiest, J., Brubaker, L.H., Kadlubar, F.F., and Lucier, G.W. Genotype/phenotype discordance for human arylamine N-acetyltransferase (NAT2) reveals a new slow-acetylator allele common in African-Americans. *Carcinogenesis* 14: 1689-1692, 1993.
 37. Delomenie, C., Sica, L., Grant, D.M., Krishnamoorthy, R., and Dupret, J.-M. Genotyping of the polymorphic N-acetyltransferase (NAT2*) gene locus in two native African populations. *Pharmacogenetics* 6: 177-185, 1996.
 38. Lin, H.J., Han, C.-Y., Lin, B.K., and Hardy, S. Ethnic distribution of slow acetylator mutations in the polymorphic N-acetyltransferase (NAT2) gene. *Pharmacogenetics* 4: 125-134, 1994.
 39. Shishikura, K., Hohjoh, H., and Tokunaga, K. Novel allele containing 190C>T nonsynonymous substitution in the N-acetyltransferase (NAT2) gene. *Hum. Mut.* 15: 581, 2000.
 40. Blum, M., Heim, M., and Meyer, U.A. Nucleotide sequence of rabbit NAT1 encoding monomorphic arylamine N-acetyltransferase. *Nucleic Acids Res.* 18:5287, 1990.
 41. Sasaki, Y., Ohsako, S., and Deguchi, T. Molecular and genetic analyses of arylamine N-acetyltransferase polymorphism of rabbit liver. *J. Biol. Chem.* 266:13243-13250, 1991.
 42. Martell, K.J., Vatsis, K.P., Weber, W.W. Molecular genetic basis of rapid and slow acetylation in mice. *Mol. Pharmacol.* 40:218-227, 1991.
 43. Martell, K.J., Levy, G.N., Weber, W.W. Cloned mouse N-acetyltransferases: Enzymatic properties of expressed Nat-1 and Nat-2 gene products. *Mol. Pharmacol.* 42:265-272, 1992.

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

44. Fretland, A.J., Doll, M.A., Gray, K., Feng, Y., and Hein, D.W. Cloning, expression and recombinant expression of NAT1, NAT2, and NAT3 derived from C3H/HeJ (rapid) and A/HeJ (slow) acetylator inbred mouse: Functional characterization of the activation and deactivation of aromatic amine carcinogens. *Toxicol. Appl. Pharmacol.* 142:360-366, 1997.
45. Abu-Zeid, M., Nagata, K., Miyata, M., Ozawa, S., Fukuhara, M., Yamazoe, Y., and Kato, R. An arylamine acetyltransferase (AT-I) from Syrian golden hamster liver: Cloning, complete nucleotide sequence, and expression in mammalian cells. *Mol. Carcinogen.* 4:81-88, 1991
46. Nagata, K., Ozawa, S., Miyata, M., Shimada, M., Yamazoe, Y., and Kato, R. Primary structure and molecular basis of polymorphic appearance of an acetyltransferase (AT-II) in hamsters. *Pharmacogenetics* 4:91-100, 1994.
47. Ferguson, R.J., Doll, M.A., Rustan, T.D., Baumstark, B.R., and Hein, D.W. Syrian hamster monomorphic N-acetyltransferase (NAT1) alleles: amplification, cloning, sequencing, and expression in E. coli. *Pharmacogenetics* 4:82-90, 1994.
48. Doll, M.A., and Hein, D.W. Cloning, sequencing, and expression of NAT1 and NAT2 encoding genes from rapid and slow acetylator inbred rats. *Pharmacogenetics* 5:247-251, 1995.
49. Ohsako, S., Ohtomi, M., Sakamoto, Y., Uyemura, K., and Deguchi, T. Arylamine N-acetyltransferase from chicken liver: II. Cloning of cDNA and expression in Chinese hamster ovary cells. *J. Biol. Chem.* 263:7534-7538, 1988.
50. Blum, M., Grant, D.M., Demierre, A., and Meyer, U.A. Nucleotide sequence of a full-length cDNA for arylamine N-acetyltransferase from rabbit liver. *Nucleic Acids Res.* 17:3589, 1989.
51. Blum, M., Grant, D.M., Demierre, A., and Meyer, U.A. N-acetylation pharmacogenetics: A gene deletion causes absence of arylamine N-acetyltransferase in liver of slow acetylator rabbits. *Proc. Natl. Acad. Sci. USA* 86:9554-9557, 1989.
52. Blum, M., Heim, M., and Meyer, U.A. Nucleotide sequence of rabbit NAT2 encoding polymorphic liver arylamine N-acetyltransferase (NAT). *Nucleic Acids Res.* 18:5295, 1990.
53. Ferguson, R.J., Doll, M.A., Baumstark, B.R., and Hein, D.W. Polymorphic arylamine N-acetyltransferase encoding gene (NAT2) from homozygous rapid and slow acetylator congenic Syrian hamsters. *Gene* 140:247-249, 1994.
54. Ferguson, R.J., Doll, M.A., Rustan, T.D., and Hein, D.W. Cloning, expression and functional characterization of rapid and slow acetylator polymorphic N-acetyltransferase encoding genes of the Syrian hamster. *Pharmacogenetics* 6:55-66, 1996.
55. Doll, M.A. and Hein, D.W. Rattus norvegicus polymorphic N-acetyltransferase slow form (NAT2*21B) gene, complete coding sequence. *Genbank* U23418, 1995.
56. Watanabe, M., Sofuni, T., and Nohmi, T. Involvement of Cys69 residue in the catalytic mechanism of N-hydroxyarylamine O-acetyltransferase of Salmonella typhimurium: Sequence similarity at the amino acid level suggests a common catalytic mechanism of acetyltransferase for S. typhimurium and higher organisms. *J. Biol. Chem.* 267:8429-8436, 1992.
57. Blattner, F.R., Plunkett, G. III., Mayhew, G.F., Perna, N.T. and Glasner, F.D. *Genbank* P77567, 1997.

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

58. Payton, M., Auty, R., Delgoda, R., Everett, M., and Sim, E. Cloning and characterization of arylamine N-acetyltransferase genes from *Mycobacterium smegmatis* and *mycobacterium tuberculosis*: increased expression results in isoniazid resistance. *J. Bacteriol.* 181:1343-1347, 1999.
59. Yang, M., Katoh, T., Delongchamp, R., Ozawa, S., Kohshi, K., and Kawamoto, T. Relationship between NAT1 genotype and phenotype in a Japanese population. *Pharmacogenetics* 10: 225-232, 2000.
60. Johnson, N., Bell, P., Jonovska, V., Budge, M. and Sim, E. NAT polymorphisms and susceptibility to Alzheimer's disease: identification of a novel NAT1 allelic variant. *BMC Medical Genetics* 5:6 (9 pages) 2004.
61. Lo-Guidice, J.-M., Allorge, D., Chevalier, D., Debuysere, H., Fazio, F., Lafitte, J.-J., and Broly, F. Molecular analysis of the N-acetyltransferase 1 gene (NAT1*) using polymerase chain reaction-restriction fragment-single strand conformation polymorphism assay. *Pharmacogenetics* 10: 293-300, 2000.
62. Trepanier, L.A., Cribb, A.E., Spielberg, S.P. and Ray, K. Deficiency of cytosolic arylamine N-acetylation in the domestic cat and wild felids caused by the presence of a single NAT1-like gene. *Pharmacogenetics* 8: 169-179, 1998.
63. Trepanier, L.A., Ray, K., Winand, N., Spielberg, S.P., Cribb, A.E. Cytosolic arylamine N-acetyltransferase deficiency in the dog and other canids due to an absence of NAT genes. *Biochem. Pharmacol.* 54: 73-80, 1997.
64. Cascorbi, I., Roots, I., and Brockmoller, J. Homo sapiens arylamine N-acetyltransferase 1 (NAT1) gene, NAT1*11C allele, complete cds. *Genbank* AF308866, 2000.
65. Lee, Soo-youn (Email: lsy117@hanmail.net) and Kim, Jong-Won (Email: jwonk@smc.samsung.co.kr), personal communication.
66. Sekine, A., Saito, S., Iida, A., Mitsunobu, Y., Higuchi, S., Harigae, S. and Nakamura Y.: Identification of single-nucleotide polymorphisms (SNPs) of human N-acetyltransferase genes NAT1, NAT2, AANAT, ARD1, and L1CAM in the Japanese population. *J. Hum. Genet.* 46: 314-319, 2001.
67. Dandara, C., Masimirembwa, C.M., Magimba, A., Kaaya, S., Sayi, J., Sommers, D.K., Snyman, J.R., and Hasler, J.A.: Arylamine N-acetyltransferase (NAT2) genotypes in Africans: the identification of a new allele with nucleotide changes 481C>T and 590G>A. *Pharmacogenetics* 13: 55-58, 2003.
68. Lee, S.Y, Lee, K.A, Ki, C.S., Kwon, O.J., Kim, H.J., Chung, M.P., Suh, G.Y., and Kim, J.W.: Complete sequencing of a genetic polymorphism in NAT2 in the Korean population. *Clin. Chem.* 48: 775-777, 2002.
69. Zhu, Y., Doll, M.A. and Hein, D.W.: Functional genomics of C190T single nucleotide polymorphism in human N-acetyltransferase 2. *Biol. Chem.* 383: 983-987, 2002.
70. Kelly, S.L. and Sim, E.: Arylamine N-acetyltransferase in Balb/c mice: Identification of a novel mouse isozyme by cloning and expression in vivo. *Biochem. J.* 302: 347-353, 1994.
71. Boukouvala, S., Price, N. and Sim, E.: Identification and functional characterization of novel polymorphisms associated with genes for arylamine N-acetyltransferases in mice. *Pharmacogenetics* 12: 385-394, 2002.
72. Anitha, A., and Banerjee, M.: Arylamine N-acetyltransferase 2 polymorphism in the ethnic populations of South India. *Int. J. Mol. Med.* 11: 125-131, 2003.

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

73. Doll, M.A., Zang, Y., Yeager, M., Welch, R., Chanock, S. and Hein, D.W.: Homo sapiens N-acetyltransferase (NAT2) gene, NAT2*5I allele, complete cds. *GenBank* AY23052, 2003.
74. Doll, M.A., Zang, Y., Yeager, M., Welch, R., Chanock, S. and Hein, D.W.: Homo sapiens N-acetyltransferase (NAT2) gene, NAT2*12D allele, complete cds. *GenBank* AY23051, 2003.
75. Tanira, M.O.M., Simsek, M., Al Balushi, K., Al Lawatia, K., Al Barawani, H., and Bayoumi, R.A.: Distribution of arylamine N-acetyltransferase 2 (NAT2) genotypes among Omani Arabs. *SQU J. Sci. Res.: Med. Sci.*5: 9-14, 2003.
76. Walraven, J.M., Doll, M.A. and Hein, D.W.: Identification and characterization of functional rat arylamine N-acetyltransferase 3: Comparisons with rat arylamine N-acetyltransferases 1 and 2. *J. Pharmacol. Exper. Ther.* 319: 369-375, 2006.
77. Walraven, J.M., Barker, D.F., Doll, M.A. and Hein, D.W.: Tissue expression and genomic sequences of rat N-acetyltransferases rNat1, rNat2, rNat3, and functional characterization of a novel rNat3*2 genetic variant. *Toxicol. Sci.* 99: 413-421, 2007.
78. Fakis, G., Boukouvala, S., Kawamura, A., and Kennedy, S.: Description of a novel polymorphic gene encoding for arylamine N-acetyltransferase in the rhesus macaque (*Macaca mulatta*), a model animal for endometriosis. *Pharmacogenet. Genomics* 17: 181-188, 2007.
79. Badawi, A.F., Bell, D.A., Hirvonen, A., and Kadlubar, F.: Role of aromatic amine acetyltransferases, NAT1 and NAT2, in carcinogen-DNA adduct formation in the human urinary bladder. *Cancer Res.* 55: 5230-5237, 1995.
80. Bell, D.A., Badawi, A.F., Lang, N.P., Ilett, K.F., Kadlubar, F.F. and Hirvonen, A.: Polymorphism in the NAT1 polyadenylation signal: association of NAT1*10 allele with higher N-acetylation activity in bladder and colon tissue. *Cancer Res.* 55: 5226-5229, 1995.
81. Grant, D.M., Hughes, N.C., Janezic, S.A., Goodfellow, G.H., Chen, H.J., Gaedigk, A., Yu, V.L, and Grewal, R.: *Mutat. Res.* 376: 61-70, 1997.
82. Hein, D.W., McQueen, C.A., Grant, D.M, Goodfellow, G.H., Kadlubar, F.F. and Weber, W.W.: Pharmacogenetics of the arylamine N-acetyltransferases: A symposium in honor of Wendell W. Weber. *Drug Metab. Dispos.* 28: 1425-1432, 2000.
83. Fretland, A.J., Doll, M.A., Leff, M.A., and Hein, D.W.: Functional characterization of nucleotide polymorphisms in the coding region of N-acetyltransferase 1 (NAT1). *Pharmacogenetics* 11: 511-520, 2001.
84. Butcher, N.J., Boukouvala, S., Sim, E., and Minchin, R.F.: Pharmacogenetics of the arylamine N-acetyltransferases. *Pharmacogenomics J.* 2: 30-42, 2002.
85. Hein, D.W.: Molecular genetics and function of NAT1 and NAT2: role in aromatic amine metabolism and carcinogenesis. *Mut. Res.* 506-507: 65-77, 2002.
86. Zhu, Y. and Hein, D.W.: Functional effects of single nucleotide polymorphisms in the coding region of human N-acetyltransferase 1. *Pharmacogenomics J.* 8: 339-348, 2008.
87. Vaziri, S.A.J., Hughes, N.C., Sampson, H., Darlington, G., Jewett, M.A.S., and Grant, D.M.: Variation in enzymes of arylamine procardinogen biotransformation among bladder cancer patients and control subjects. *Pharmacogenetics* 11: 7-20, 2001.
88. Boukouvala, R and Fakis, G.: Arylamine N-acetyltransferases: What we learn from genes and genomes. *Drug Metab. Rev.* 37: 511-564, 2005.

Human NAT1 Alleles (Haplotypes)

(Last update May 24, 2011)

89. Sim, E., Westwood, I. and Fullman, E.: Arylamine N-acetyltransferases. *Expert Opinion in Drug Metab.. Toxicol.* 3: 169-184, 2007.
90. Hein, D.W., Ferguson, R.J., Doll, M.A., Rustan, T.D., and Gray, K.: Molecular genetics of human polymorphic N-acetyltransferase: enzymatic analysis of 15 recombinant human wild-type, mutant, and chimeric NAT2 allozymes. *Hum. Mol. Genet.* 3:729-734, 1994.
91. Hein, D.W., Doll, M.A., Rustan, T.D., and Ferguson, R.J.: Metabolic activation of N-hydroxyarylamines and N-hydroxyarylamides by 16 recombinant human NAT2 allozymes: Effects of 7 specific NAT2 nucleic acid substitutions. *Cancer Res.* 55:3531-3536, 1995.
92. Hickman, D., Palamanda, J.R., Unadkat, J.D. and Sim, E.: Enzyme kinetic properties of human recombinant arylamine N-acetyltransferase 2 allotypic variants expressed in Escherichia Coli. *Biochem. Pharmacol.* 50: 697-703, 1995.
93. Fretland, A.J., Leff, M.A., Doll, M.A. and Hein, D.W.: Functional characterization of human N-acetyltransferase 2 (NAT2) single nucleotide polymorphisms. *Pharmacogenetics* 11: 207-215, 2001.
94. Svensson, C.K. and Hein, D.W.: Phenotypic and genotypic characterization of N-acetylation. In: *Drug Metabolism and Transport: Molecular Methods and Mechanisms*. L.H. Lash, Editor, *Methods in Pharmacology and Toxicology Series*, The Humana Press, Totowa, NJ, pp. 173-195, 2005.
95. Hein, D.W.: N-acetyltransferase 2 genetic polymorphism: effects of carcinogen and haplotype on urinary bladder cancer risk. *Oncogene* 25: 1649-1658, 2006.
96. Hein, D.W., Fretland, A.J. and Doll, M.A.: Effects of single nucleotide polymorphisms in human N-acetyltransferase 2 on metabolic activation (O-acetylation) of heterocyclic amine carcinogens. *Int. J. Cancer* 119: 1208-1211, 2006.
97. Zang, Y., Zhao, S., Doll, M.A., States, J.C. and Hein, D.W.: Functional characterization of the A411T (L137F) and G364A (D122N) genetic polymorphisms in human N-acetyltransferase 2. *Pharmacogenet. Genomics* 17: 37-45, 2007.
98. Zang, Y., Doll, M.A., Zhao, S., States, J.C. and Hein, D.W.: Functional characterization of single nucleotide polymorphisms and haplotypes of human N-acetyltransferase 2. *Carcinogenesis* 28: 1665-1671, 2007.
99. Bolt, H.M., Selinski, S., Dannappel, D. Baszkewicz, M., and Golka. K.: Re-investigation of the concordance of human NAT2 phenotypes and genotypes. *Arch. Toxicol.* 79: 196-200, 2005.
100. Zhu, Y., States, J.C., Wang, Y., and Hein, D.W.: Functional effects of genetic polymorphisms in the N-acetyltransferase 1 coding and 3' untranslated regions. *Birth Defects Res. (Pt A): Clin. Mol. Teratol.* 91: 77-84, 2011.
101. Agundez, J. (unpublished)