Genes associated with metabolic syndrome and hyperuricemia: An overview

Shabnam Pokharel\textsuperscript{1*}, Sanjeev Acharya\textsuperscript{2} and Abu Taib Mohammed Mohiuddin Chowdhury\textsuperscript{3}

\textsuperscript{1}Department of Preventive Medicine, Jiamusi University, Heilongjiang Province, China
\textsuperscript{2}Department of Nephrology, 1\textsuperscript{st} Affiliated Hospital of Jiamusi University, Jiamusi city, Heilongjiang province, P. R China
\textsuperscript{3}Department of Digestive Disease, 1\textsuperscript{st} Affiliated Hospital of Jiamusi University, Jiamusi city, Heilongjiang Province, P.R China

Abstract

Purposes: Recently, different studies have found genetic basis for hyperuricemia, metabolic syndrome and different components of it. The purpose of our review is to overview the different genes that have been studied with regard to hyperuricemia, metabolic syndrome and its components.

Method: We made this review by systematically searching relevant literatures using multiple keywords and standardized terminology on PubMed, Nature.com, Hindawi.com, Plosone.com etc and other online resources related to the topic of our study.

Findings: Serum uric acid level is influenced by diet, cellular breakdown, renal elimination and correlates with metabolic syndrome, diabetes mellitus, blood pressure, gout, and cardiovascular disease. Hyperuricemia has been associated with the development of type II diabetes and risk of cardiovascular morbidity and mortality. We found associations of different genes regarding hyperuricemia, metabolic syndrome and its components like diabetes mellitus, obesity, dyslipidemia, and hypertension.

Conclusions: This review provides evidence that different genes are responsible for the causation of Metabolic syndrome and its each component. Further genetic studies with different population groups and races in different parts of the world need to be carried out to find specific relation and effect of each gene in each specific component of our study.

Introduction

Metabolic syndrome (MetS) is a constellation of metabolic abnormalities, including abdominal obesity, hypertriglyceridemia, low high-density lipoprotein (HDL) concentrations, hypertension (HTN), and hyperglycemia [1], which has strong association with the development of type II diabetes and risk of cardiovascular morbidity and mortality [2,3]. Ford et al. reported that according to International Diabetes Federation (IDF) criteria the prevalence of MS is 23% in America, and 23.50% and 14.70% in urban and rural areas in China, respectively [4]. Prevalence and incidence of MetS has increased rapidly and become a major public health challenge worldwide [5]. The etiology of the MetS is complex, determined by the interplay of both genetic and environmental factors [6].

Accordingly, the prevalence of MetS is increasing in epidemic proportions in both developed countries and developing countries [7]. The worldwide prevalence of MetS in the adult population is estimated between 20% and 25% [8]. According to data from the National Health and Nutrition Examination Survey (NHANES) 2009-2010, about one-fifth of the adult population of the United States had high cardio-metabolic risk, with the prevalence of MetS (adjusted for age) being estimated at 22.9% [9]. The prevalence of the MetS in the old aged population of China has reported to be 23% in men and 41% in women [10], about 21% in Chinese adults [11], 23.8% in US Whites, 21.6% in African Americans, and 31.9% in Mexican Americans [12,13]. The increasing prevalence of MetS poses a serious public health problem worldwide. Genetic influences are thought to play a crucial role in MetS development, and as a result, genetic studies have become an active research area.

Uric acid (UA) is a metabolic product of purine. Serum uric acid level is influenced by diet, cellular breakdown, renal elimination and correlates with metabolic syndrome, diabetes, blood pressure, gout, and cardiovascular disease. Hyperuricemia has been associated with several metabolic and cardiovascular conditions, including diabetes and coronary artery disease [14]. Some large epidemiologic studies have shown that the prevalence of MetS was positively related to serum levels of UA (SUA) [15-17]. The association between uric acid and MetS is strong throughout human development. Epidemiological studies have demonstrated a close relationship between serum uric acid (SUA) levels and the presence of MetS (and several of its components) among children and adolescents as well as adults [18]. Some studies have even noted the strong association between SUA and carotid atherosclerosis among obese children [18,19]. One study analyzed the cross-sectional data of 1,370 US children and adolescents aged 12-17 years from the National Health and Nutrition Examination Survey (NHANES) 1999-2002 and found a graded positive association between SUA and the prevalence of MetS or its components, independent of classical factors [20].

Correspondence to: Shabnam Pokharel, Department of Preventive Medicine, Jiamusi University, Heilongjiang Province, P.R China, E-mail: dramansanju@hotmail.com

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risk factors. They found that of the five components of metabolic syndrome, SUA was significantly associated with abdominal obesity, hypertiglyceridemia, and hyperglycemia; there was only a borderline association observed between SUA and high blood pressure. Many data strongly suggest that uric acid may have a pathogenic role in the development of MetS and associated cardiovascular disease. Recent studies suggest that one of the mechanisms by which low birth weight increases the risk for hypertension and diabetes later in life is because low birth weight results in an elevation of uric acid that persists from birth throughout childhood.

The familial nature of MetS, the marked difference in the prevalence among various racial groups, and differences in concordance rates between monozygotic twins clearly suggested that MetS is under genetic control. Heritability estimates for MetS range from 10% to 42% [20]. For instance, the heritability of MetS was found to be 24% among 803 individuals from 89 Caribbean-Hispanic families in the Northern Manhattan Family Study [21], 42% in 1,617 adult female twin pairs recruited from rural China with low MetS prevalence [22]. Genome-wide association studies (GWAS) have led to a remarkable increase in replicable genetic association data for SUA and gout. Reduced renal excretion of urate is the major cause of hyperuricaemia and gout and most of the common genes discovered in GWAS are involved in the renal urate-transport system.

Genetic risk factors for metabolic syndrome

Genetic factors could influence the MetS itself or each individual component of it. A family history that includes obesity, Type 2 diabetes and/or insulin resistance greatly increases the chance that an individual will develop the MetS. However, there are some genetic loci, which are in linkage disequilibrium with MetS.

Genetics of metabolic syndrome

Kissebah et al. performed a genomewide scan by use of a 10-cM map in 2,209 individuals distributed over 507 nuclear Caucasian families and for the first identifying major genetic loci influencing the MetS phenotypes. They showed a quantitative trait locus (QTL) on chromosome 3q27 strongly linked to 6 traits: weight, waist circumference, leptin, insulin, insulin/glucose ratio, and hip circumference (lod scores ranging from 2.4 to 3.5). A second QTL was found on chromosome 17p12 and was strongly linked to plasma leptin levels (lod=5.0) [23].

McCarthy et al. studied 207 SNPs in 110 candidate genes among coronary artery disease patients, a population enriched for metabolic abnormalities. The number of abnormalities (0 to 5) was determined in 214 male and 91 female patients, and the association with each polymorphism was evaluated. Polymorphisms in 8 genes were associated with metabolic syndrome in the whole population (P values ranging from 0.047 to 0.008): LDLR, GBE1, IL1R1, TGFBI, IL6, COL5A2, SELE and LIPC. Variants in 7 additional genes showed significant gene interaction by gender. Separate analyses in men and women revealed a strong association with a silent polymorphism in the gene encoding low density lipoprotein receptor-related protein-associated protein-1 (LRPAP1) among females (P=0.0003), but not males (P=0.292) [24].

In a study of MetS of animal models Vartanian et al. found that Neill knockout mice were born at expected mendelian ratios and the phenotype of Neill +/- pups was normal through the first 4 to 6 months of life. At about 7 months, however, male Neill +/- mice developed severe obesity, and female Neill +/- mice were modestly overweight. Mutant mice also showed dyslipidemia, fatty liver disease, and a tendency to develop hyperinsulinemia, similar to metabolic syndrome in humans. Histologic studies showed significant kidney vacuolization, and mitochondrial DNA from Neill +/- mice showed increased levels of steady-state DNA damage and deletions, compared to wild type control [25]. Different genes for genetic association studies with metabolic syndrome are shown in Table 1 [26].

| Table 1. Different genes for genetic association studies with metabolic syndrome. |
|-----------------------------|
| **LOW DENSITY LIPOPROTEIN RECEPTOR (LDLR) gene.** The low density lipoprotein receptor is a cell surface receptor that plays an important role in cholesterol homeostasis. Mutations in this gene are associated with familial hypercholesterolemia. |
| **GLYCOGEN BRANCHING ENZYME (GBE1) gene.** The GBE1 gene encodes the glycogenic branching enzyme (EC 2.4.1.18), which is involved in glycogen synthesis. Branching of the glycogen chains is essential to pack a very large number of glycosyl units into a relatively soluble spherical molecule of glycogen. |
| **INTERLEUKIN 1 RECEPTOR, TYPE 1 (IL1R1) gene.** Interleukin-1 consists of 2 separate but related proteins, IL-1-alpha and IL-1-beta. Both contain a single membrane-spanning segment, a large cytoplasmic region, and an extracellular domain. IL-1 is one of mediators in inflammation. |
| **TRANSFORMING GROWTH FACTOR, BETA-1 (TGFBI) gene.** This gene encodes the multifunctional peptide that controls proliferation, differentiation, and other functions in many cell types. TGFβ acts synergistically with TGFα in inducing transformation. It also acts as a negative autocrine growth factor. Dysregulation of TGFβ activation and signaling may result in apoptosis. |
| **INTERLEUKIN 6 (IL6) gene.** IL6 is an immunoregulatory cytokine that activates a cell-surface signaling assembly composed of IL6, IL6RA, and the shared signaling receptor gp130. The aberrant production of IL6 by neoplastic cells has been implicated as a strong contributory factor to the growth of multiple myeloma and other B-cell dyscrasias, T-cell lymphoma, renal and ovarian cell carcinomas, and Kaposi sarcoma demonstrated repression of the IL6 gene promoter by p53. IL6 gene is one of the candidate genes for linkage studies of osteopenia and osteoporosis because the gene product stimulates osteoclasts through binding to its cell surface receptor (IL6R). |
| **COLLAGEN, TYPE V, ALPHA-2 (COL5A2) gene.** SELECTIN E (SELE) gene. Endothelial leukocyte adhesion molecule-1 is expressed by cytokine-stimulated endothelial cells. It is thought to be responsible for the accumulation of blood leukocytes at sites of inflammation by mediating the adhesion of cells to the vascular lining. |
| **HEPATIC LIPOPROTEIN LIPASE (LIPC) gene.** Hepatic lipase, like lipoprotein lipase and lecithin:cholesterolacyltransferase, plays a major role in the regulation of plasma lipids. Rare deficiencies of all of these enzymes have been identified in man, and all are associated with pathologic levels of circulating lipoprotein particles. |

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The common human obesity is thought to be oligogenic state and its expression is modulated by multiple modifier genes and by environmental factors: food intake, physical activity, and smoking. Genetic basis in the pathophysiology of obesity is estimated to be 40-80%. At least 204 putative gene loci associated with obesity have been identified, and those, which have been confirmed by multiple studies, are presented in Table 2 [26].

**Genetic predisposition to hyperuricemia**

Elevated serum uric acid is a risk factor for gout and is independently associated with cardiovascular disease in the general population and is also linked to insulin resistance, type 2 diabetes, MetS and obesity. Although conventional factors, including age, body mass index (BMI), alcohol consumption and cigarette smoking, contribute greatly to variations in SUA concentrations [27], genetic determinants also play roles, and heritability as high as 42% have been reported [28]. Moreover, genetic studies facilitate the development of effective treatments for associated diseases. Recently, advances have been made in identifying genes regulating SUA through GWAS. The first wave of discovery of uric acid genes was conducted with European populations, identifying the associations of SLC2A9, ABCG2, and SLC17A3 with SUA concentrations [29-31]. In addition, many GWAS focusing on SUA concentrations in individuals of European decent have identified several novel associated loci mapped in or near SLC17A1, SLC22A11, SLC22A12, SLC16A9, LRRC16A, GCKR, R3HD2M2- INHBC, and RREB1 [32-34].

In a study done at Shanghai, China which aimed to evaluate the associations between these loci and serum uric acid concentrations, fourteen single nucleotide polymorphisms (SNPs) mapped in or near 11 loci (PDZK1, GCKR, LR2, SLC2A9, ABCG2, LRRC16A, SLC17A1, SLC17A3, SLC22A11, SLC22A12 and SFI) were genotyped in 2329 Chinese subjects. Serum biochemical parameters including uric acid concentrations were determined. All the variants were analyzed for gender differences since uric acid metabolism differed between genders. The meta-analysis for combined data from both males and females revealed that rs3775948 and rs606458 were associated with the uric acid concentrations P=0.036 and 0.043, respectively. Study females revealed that rs3775948 and rs606458 were associated with SUA concentrations [35]. The meta-analysis for combined data from both males and females revealed that rs3775948 and rs606458 were associated with SUA concentrations [35].

Table 2. Genetic predisposition to obesity.

| Gene name (accord. to HUGO nomenclature committee) | Protein name |
|---------------------------------------------------|--------------|
| ADIPOQ                                            | Adiponectin   |
| ADR2A                                             | Adrenergic receptor α-2A |
| ADR2B                                             | Adrenergic receptor α-2B |
| ADRB1                                             | Adrenergic receptor β-1 |
| ADRB2                                             | Adrenergic receptor β-2 |
| ADRB3                                             | Adrenergic receptor β-3 |
| DRD2                                              | Dopamine receptor D2 |
| LEP                                               | Leptin        |
| LEPR                                              | Leptin receptor |
| NR3C1                                             | Nuclear receptor subfamily 3, group C, member 1 |
| PPARγ                                             | PPAR-γ       |
| UCP1                                              | Uncoupling protein 1 |
| UCP2                                              | Uncoupling protein 2 |
| UCP3                                              | Uncoupling protein 3 |
| TNF                                               | TNF-α        |
| LIPE                                              | Hormone sensitive lipase |

while SF1 rs606458 and SLC2A9 rs3775948 are associated with the uric acid concentrations in both Chinese males and females [35].

The genes for the urate transporters, GLUT-9 and ABCG2, which are important modulators of uric acid levels, consistently associate with serum uric acid levels and gout. Although the GWAS association data for SLC22A12 (which encodes URAT1) have been less impressive, many layers of evidence indicate that URAT1 is an essential component of renal urate handling. Loss-of-function mutations in the absorptive transporter genes SLC22A12 or SLC2A9 lead to a dominance of urate secretion and hypouricaemia, whereas loss-in-function or reduction-in-function mutations in the secretory urate transporter genes, ABCG2, SLC17A1 or SLC17A3, cause hyperuricaemia. These findings indicate that serum uric acid levels are largely determined by the relative balance between urate absorption and secretion across the proximal tubule [36].

**Genetics of hypertension**

Genetics of hypertension is complex with no known single gene playing a major role, but rather many genes each with mild effects reacting to different environmental stimuli contribute to blood pressure. The heritable component of blood pressure has been documented in familial and twin studies suggesting that 30%-50% of the variance of blood pressure readings is attributable to genetic heritability and about 50% to environmental factors. Early studies in hypertension identified specific enzymes, channels and receptors implicating sodium handling in the regulation of blood pressure. It included genes involved with the renin-angiotensin-aldosterone system controlling blood pressure and salt-water homeostasis, proteins in hormonal regulation of blood pressure and proteins coded by genes involved in the structure and/or regulation of vascular tone (endothelins and their receptors). The field of molecular genetics has revolutionized the study of hypertension by identifying single gene syndromes or Mendelian forms and several candidate genes for blood pressure variance. Genes have been localized to at least 20 chromosome regions. For example, recent GWAS of common genetic variants found 13 single nucleotide polymorphisms (SNPs) or variants in systolic and 20 for diastolic blood pressure readings representing different genes and genetic heterogeneity.

The CYP17A1 gene: It is located on chromosome 10q24.3, consisting of eight exons and seven introns, and is primarily expressed in the adrenal glands and gonads. The CYP17A1 gene produces the P450c17 protein, which is a key enzyme in the steroid-genic pathway that produces sex hormones. Some evidence has indicated that the levels of sex hormones could affect the development of cardiovascular and cerebrovascular diseases [37]. This gene was shown to be consistently and significantly associated with SBP and DBP in the two large GWA meta-analyses, the Cohorts for Heart and Aging Research in Genome Epidemiology (CHARGE) Consortium and the Global Blood Pressure Genetics (Global BPgen) Consortium, and subsequently cross-validated in Korean and Japanese populations [38,39].

ATP2B1 gene: GWAS studies showed that the rs2681472 polymorphism near the ATP2B1 gene was associated with hypertension susceptibility in Europeans. The meta-analysis confirmed that there is a significant association of the ATP2B1 gene polymorphism with hypertension susceptibility in East Asians [40].

The STK39 gene: It encodes the Ste20-related prolinealanine-rich kinase (SPAK) protein, which may regulate BP by increasing its expression and altering renal sodium excretion through its interaction with WNK kinase and cation-chloride cotransporters. A meta-analysis
Both genes are part of the ATP-sensitive potassium channel, which as the potassium channel, inwardly rectifying subfamily J, member 11). The gene encodes the high-affinity sulfonylurea receptor (SUR1) subunit and the latter can be distinguished from monogenic Mendelian diseases. From them, HNF4A, TCF1 (or HNF1A) and GCK genes which include maturity-onset diabetes of the young, gestational diabetes, and diabetes secondary to various metabolic disorders or the result of corticosteroid treatment. Now, there has been found a lot of genetic basis for the causation of different types of DM.

Affected genes in monogenic forms of diabetes, insulin resistance and lipodystrophy represent an excellent base for the search of susceptibility genes for polygenic multifactorial Type 2 DM, although the latter can be distinguished from monogenic Mendelian diseases. Namely, on certain genetic backgrounds, with particular gene interaction – epistasis and with certain environment influence the same genes could contribute to Type 2 DM.

Maturity-onset diabetes of the young (MODY) is a monogenic form of diabetes and exists in 6 forms due to 6 affected MODY genes. From them, HNF4A, TCF1 (or HNF1A) and GCK genes which encode for two transcriptional factors and glucokinase in the β-cells, respectively were reliably proved to be involved in DM2.

PPARγ (peroxisome proliferator-activated receptor-γ). This gene has been widely studied because it is important in adipocyte and lipid metabolism. One form of the PPARγ gene (Pro) decreases insulin sensitivity and increases Type 2DM risk by several fold. A study done by Laccarino et al. demonstrated that hypertensive patients bearing the Glu27 variant of β2AR gene and treated with b-blockers show a higher incidence of dyslipidemia. This result allows the identification of patients at high risk to develop metabolic complications to chronic b-blockade treatment[46].

Conclusion

This review provides evidence that different genes are responsible for the causation of MetS and different components of it. When studying the importance of particular susceptibility genes one must bear in mind that their effect is modest and different factors may affect
it. Further genetic studies with different population groups and races in different parts of the world are needed to be carried out to find specific relation of each gene regarding each specific component of our study. The listed susceptibility genes do contribute to the basis for future diagnosis, prognosis and therapy for hyperuricemia and MetS, but the mutual influences of various gene loci and interactions of genes with dietary, environmental and other lifestyle factors remain to be exactly determined and quantitated.

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