Mutation Analysis of Candidate Genes SCN1B, KCND3 and ANK2 in Patients with Clinical Diagnosis of Long QT Syndrome

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Summary
The long QT syndrome (LQTS) is a monogenic disorder characterized by prolongation of the QT interval on electrocardiogram and syncope or sudden death caused by polymorphic ventricular tachycardia (torsades de pointes). In general, mutations in cardiac ion channel genes (KCNQ1, KCNH2, SCN5A, KCNE1, KCNE2) have been identified as a cause for LQTS. About 50-60 % of LQTS patients have an identifiable LQTS causing mutation in one of mentioned genes. In a group of 12 LQTS patients with no identified mutations in these genes we have tested a hypothesis that other candidate genes could be involved in LQTS pathophysiology. SCN1B and KCND3 genes encode ion channel proteins, ANK2 gene encodes cytoskeletal protein interacting with ion channels. To screen coding regions of genes SCN1B, KCND3, and 10 exons of ANK2 following methods were used: PCR, SSCP, and DNA sequencing. Five polymorphisms were found in screened candidate genes, 2 polymorphisms in KCND3 and 3 in SCN1B. None of found polymorphisms has coding effect nor is located close to splice sites or has any similarity to known splicing enhancer motifs. Polymorphism G246T in SCN1B is a novel one. No mutation directly causing LQTS was found. Molecular mechanism of LQTS genesis in these patients remains unclear.

Key words
ANK2 • Candidate genes • KCND3 • Long QT syndrome • SCN1B

Introduction

The long QT syndrome (LQTS) is a monogenic disorder characterized by prolongation of the QT interval on electrocardiogram and syncope or sudden death caused by polymorphic ventricular tachycardia (torsades de pointes). In general, mutations in cardiac ion channel genes (KCNQ1, KCNH2, SCN5A, KCNE1, KCNE2) have been identified as a cause for LQTS (Splawski et al. 2000). Recently, mutation in cytoskeletal protein gene ANK2 has also been linked to LQTS in one French family (Mohler et al. 2003, 2004). About 50-60 % of LQTS patients have an identifiable LQTS-causing mutation in one of the 5 most prevalent cardiac channel genes (Tester et al. 2005). In the others the disease mechanism remains unclear. The aim of this study is to test the hypothesis that other cardiac ion channel genes could be involved in LQTS pathophysiology: SCN1B gene encodes β1 subunit of cardiac Na+ channel and plays an important role in channel inactivation (Wallace et al. 2002). KCND3 is a gene that encodes the K+ channel that underlies the potassium transient outward current Ito in the human ventricle (Dixon et al. 1996). Targeted mutational analysis of ANK2 was also completed.

Methods

Group of patients
The group of patients was recruited from...
25 unrelated individuals who were consecutively referred to the Department of Internal Medicine and Cardiology with suspicion on LQTS. They were examined clinically including bicycle ergometry. In all of them intermediate or high probability of LQTS was present based on diagnostic score (Schwartz et al. 1993). In this scoring system various point values are assigned to various symptoms, a value of 2-3 indicates intermediate probability and ≥4 points indicates high probability of LQTS diagnosis.

Informed consent was obtained from all the individuals and peripheral blood samples were taken. Mutational analysis of KCNQ1, KCNH2, SCN5A, KCNE1 and KCNE2 genes was performed by methods published elsewhere (Splawski et al. 2000). In 11 patients the KCNQ1 gene mutations and in 2 patients the KCNH2 gene mutations were present. In the other 12 patients no mutation in the above mentioned LQTS related genes was found. These 12 individuals were subjects of this study – mutational analysis was extended to following genes: SCN1B, KCNBD3 and exons 36-37 and 39-46 of ANK2. The brain-specific exon 38 was not analyzed in this study. Clinical characteristics of study subjects are summarized in Table 1.

Table 1. Clinical characteristics of study subjects.

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Genomic DNA Extraction and PCR

Genomic DNA was extracted from samples of peripheral blood according to the standard protocol using DNA BloodSpin Kit and the standard chloroform/ethanol method. Eleven oligonucleotide primer pairs were used to amplify coding area of KCNBD3, as proposed by Postma et al. (2000), only the fifth segment of the first coding exon had different reverse primer (GGT CAT CCA GCT GCC CTC CAA CCT), which agrees with sequence of KCNBD3 in NCBI database (accession number NT 019273). Ten primer pairs were disposed to amplify chosen exons of ANK2 (from 36 to 46 except 38). These primers were taken from Mohler et al. (2003). For the PCR amplification of SCN1B gene coding and UTR region were suggested primers using Primer3 (Rozen and Skaletsky 2000), (Table 2). Sequences of these primers agree with sequence of SCN1B in Ensembl database (© 2006 WTSI / EBI, ENSG00000105711).

SSCP analysis

For the analysis of KCNBD3 and ANK2 3μl aliquots of the amplified sample were mixed with 5 μl of bromophenol blue loading dye, for analysis of SCN1B 1 μl aliquots of the amplified sample were mixed with 3 μl of bromophenol blue loading dye and 6 μl of destilated water. Samples were subsequently denatured by heating at 94 °C for 5 min, and placed into cold water to avoid renaturation. Then the samples were loaded on 9 % (KCNBD3), 11 % (ANK2) and 10 % (SCN1B) non-denaturing PAA gel. Electrophoresis was performed at 200 V and 10 °C for 3 h (KCNBD3 and ANK2) and at 120 V and 18 °C for 12 h (all exons of SCN1B except exon 3). Exon 3 was performed at 10 °C.
DNA sequencing

Genomic DNA obtained from 12 unrelated LQTS patients was screened for mutations in the coding regions of the genes SCN1B, KCND3 and a part of the gene ANK2 using SSCP analysis. If we have found three or four single strand bands in the SSCP patterns then we have done sequencing with forward and reverse sequencing primers. For purification of the amplified samples MinElute PCR Purification Kit (QIAGEN) was used. For cycle sequencing we used Big Dye Terminator Kit (Applied Biosystems) and for purification of samples after cycle sequencing DyeEx2.0 Spin Kit (Qiagen). Exons were sequenced by instrument ABI PRISM 310 (Applied Biosystems, USA).

Results

The result of the mutation screening is listed in the Table 3. None of found SNPs led to amino acid changes, were located close to splice sites or had any similarity to known splicing enhancer motifs.

Discussion

About 50-60 % of LQTS patients have an identifiable LQTS-causing mutation in one of the five most prevalent cardiac channel genes. In the others the pathophysiology remains unknown. Possible mechanisms include involvement of other ion channels but also regulatory and other proteins. Recently, possible link to LQTS was found in several new genes: KCNJ2 mutations in Andersen-Tawil syndrome (Tawil et al. 1994, Plaster et al. 2001), CACNA1c mutation in Timothy syndrome (Splawski et al. 2005), CAV3 and SCN4B mutations in some LQTS patients (Vatta et al. 2006, Medeiros-Domingo et al. 2007). These are either rare complex neurological disorders (prolonged QT interval being not the leading symptom) or there are only anecdotal cases.
Thus it is still discussed if these diseases should be included among LQTS.

In this study we tested the hypothesis of other ion channels involvement. Three candidate genes were chosen for mutational analysis in 12 patients with clinical diagnosis of LQTS. *KCND3* encodes the K+ channel that underlies the potassium transient outward current $I_{to}$ in the human ventricle (Dixon *et al.* 1996). $I_{to}$ is especially important during the early phase of repolarization, as it sets the plateau voltage of both action potential (Tseng 1999).

In contrast to other genes, *ANK2* does not encode an ion channel but encodes a structural protein called ankyrin B that is most likely implicated in ion channels anchoring to the cellular membrane. A clue to the basis of this variant emerged from a study by Chauhan *et al.* (2000), in which sodium channel activity was altered in mice lacking ankyrin B – not an ion channel protein, but an adaptor protein that associated with cytoskeletal interactions. In this study, the ankyrin B spectrin-binding domain encoded by exons 36 and 37 of *ANK2* and the entire C-terminal domain encoded by exons 39-46 were screened. The brain-specific exon 38 and membrane-binding domain were not analyzed in this study.

*SCN1B* encodes the voltage-gated Na+ -channel β1 subunit (*SCN1B*). *SCN1B* is expressed in brain, skeletal muscle and heart. The α subunit alone can display functional channel properties, but requires the β subunits to modulate Na+ -channel inactivation. Mutations in Na+-channel genes are known to cause paroxysmal excitability phenomena in skeletal muscle (myotonia, periodic paralysis) and heart (long QT syndrome) (Wallace *et al.* 2002). In the mutation database (Stenson *et al.* 2003) only one mutation in the *SCN1B* gene has been published. It is the substitution mutation C387G (on protein level C121W). This mutation causes a disruption of disulfide bridge and may alter the secondary structure of the extracellular domain (Wallace *et al.* 2002).

In our study, two allelic variants were found in *KCND3*. All variants were single nucleotide polymorphisms (SNPs) in coding regions. None of the coding SNPs led to amino acid changes, was located close to splice sites or had any similarity to known splicing enhancer motifs (Liu *et al.* 1998). All SNPs in *KCND3* were described in normal population too (Frank-Hansen at al. 2005). We assume that all the changes detected in the LQTS patients were normal variants.

No allelic variant has been found in *ANK2* gene. Three allelic variants (all SNPs) were found in *SCN1B* gene, two of them T9204C and A9248C were detected previously (Ensembl database, © 2006 WTSI / EBI, ID:ENSG00000105711), G246T has not been published yet. By the help of ESEfinder Release 2.0 (Cartegni *et al.* 2003) we have found that G246T and T9204C substitution does not have any influence on DNA splicing. The substitution A9248C causes loss of one binding place for SC35 and SRp40 splicing proteins.

The fact that no mutations have been found, can have several reasons. The SSCP methodology can detect 88 and 90 % of mutations (Fodde and Losekoot 1994) and therefore we can not fully exclude the presence of mutations within analyzed genes in these individuals. The SSCP method is sensitive for the detection of point mutations or small deletions, but it can possibly miss large deletions. The SSCP method is the most widely used screening method because of its relative simplicity and low costs. Compared to more advanced methods, such as TmHPLC (Temperature Modulated High-Performance Liquid Chromatography) the SSCP has relatively low sensitivity.

LQTS causing mutations could also present in such regions of ion channel genes which are usually not examined. Alternatively, intronic mutations or mutation in the promoter and regulatory regions could be responsible for the disease symptoms. The possibility of other than ion channel genes being involved in the etiology of the long QT syndrome should not be refused, because of huge genetic heterogeneity of this disorder (see the above mentioned genes with recently discovered possible link to QT interval prolongation). This heterogeneity makes genetic testing much more difficult than in case if a single gene were responsible for the disease.

Molecular mechanism of LQTS genesis in our group of patients remains unclear.

**Conflict of Interest**

There is no conflict of interest.

**Acknowledgements**

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References


