Characterization of a novel pathogenic variation c.1237T>G in the FZD4 gene presenting new inheritance from an Iranian individual suffering vitreoretinopathy

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1. Introduction

Familial retinopathy of prematurity and exudative vitreoretinopathy (MIM number: 133780) are rare disorders with retinal vascular development abnormalities which are inherited as autosomal dominant, autosomal recessive, or X-linked traits. Clinical synopsis is asymmetric and variable (1). Although Symptoms of the diseases vary widely from mild signs to blindness, a remarkable hallmark is defective retinal angiogenesis, which causes retinal avascularity and subsequently depending on the ischemic rate causes hyperpermeable blood vessels, revascularization, vitreoretinal traction, retinal folds, and retinal detachment (2-4).

Occurring mutations in five genes cause vitreoretinopathy including; NDP, FZD4, LRP5, TSPAN12, and ZNF408 (1,4-9). Four of them including NDP, FZD4, LRP5, and TSPAN12 have a central role in Norrin/Frizzled4 signaling, and show a significant role for this pathway in retinal angiogenesis (10). Of these genes, FZD4 mutations are mostly inherited as autosomal dominant traits. This gene belongs to the frizzled gene family (seven-transmembrane domain receptors). They are receptors for Wnt proteins and norrin (NDP) and therefore contribute to vascularization of retina (1).

In recent years, next generation sequencing (NGS) has improved our knowledge about genetic and molecular bases of various spectrums of genetic disorders. With a multilateral vision, NGS, which has rapidly progressed has helped us to find out not only new disease causing variations but also new unreported inheritances, symptoms and has shed light on the way of knowing genetic roles (11-13).

Here we report a single nucleotide variation in an Iranian patient with retinopathy using Exome sequencing. We suggest that the FZD4 gene might be causative for both autosomal recessive as well as autosomal dominant vitreoretinopathy.

SUMMARY

Whole Exome Sequencing (WES) has been used increasingly in genetic determination of various known and unknown genetic disorders. Various genes are involved in the development of the vascular network of retina. Assessment of a collection of these genes could be provided by WES. Here we used WES for a patient suffering vitreoretinopathy to detect the disease causing variant. Sanger sequencing has been applied for variant verification and allelic segregation. After analysis of WES data we found a new variant c.1237T>G in the FZD4 locus which causes retinopathy of prematurity and exudative vitreoretinopathy (MIM number: 133780). Sanger sequencing showed this single nucleotide variation inherited as homozygous in the patient and heterozygous in her unaffected parents. Notably, bioinformatics analysis predicted the variant as disease causing and it has not been described yet in home datasets and public SNP databases. FZD4 mutations are mostly inherited as autosomal dominant traits. Our findings showed the first autosomal recessive inheritance of the FZD4 gene related retinopathy. On the other hand, our data shed light on the significance of an Exome sequencing application as a genetic test to identify and characterize the comprehensive spectrum of genetic variation and classification for patients with retinopathies.

Keywords: exome sequencing, FZD4, vitreoretinopathy, autosomal recessive
2. Patients and Methods

2.1. Case report

Patient & her parents were recruited from southwest Iran. The proband was a 20-year-old girl with strabismus, horizontal nystagmus, decreased visual acuity, and retinal defects.

2.2. Peripheral blood samples

10 mL of peripheral blood was withdrawn from each of the enrolled patient and her parents, which were collected in EDTA tubes.

2.3. DNA extraction

Genomic DNA was extracted using the standard salting out protocol. The quality and quantity of the extracted DNA samples were checked by gel electrophoresis and Nano-drop.

2.4. Exome sequencing

We applied whole Exome sequencing for the patient. Sample was subjected to Exome enrichment with the sure select v6 followed by sequencing using the Illumina HiSeq 2000 genome analyzer platform (CNAG).

2.5. Sanger Validation

PCR (Polymerase chain reaction) using primers designed by Oligo 7 with the forward 5-AACTGACTGGCTTGTGCTATG-3 and reverse primer TGGATGCCCCACAAACACCAGAC-3. The PCR was conducted using Master Mix (Amplicon, Denmark) amplified targeted region of the FZD4 gene. PCR program was chosen as an initial denaturation at 95°C for 5 min, 35 cycles of 95°C for 30 sec, annealing at 60°C for 30 sec, extension at 72°C for 30 s, and a final extension at 72°C for 5 min.

PCR products have directly been sequenced and analyzed using the ABI Prism 3700 automated genetic analyzer (Applied Biosystems). The results were analyzed with Chromas LITE 2.1.1, and then compared with the reference gene sequence using the CLUSTALW (Kyoto University Bioinformatics Center). Finally, the parent analysis and bi-directional sequencing confirmed the presence of the detected mutation.

2.6. In-silico analysis

There are many and various tools for prediction of pathogenicity of variations in genes coding and non-coding regions. In the present study, we used some of these tools for evaluation of disease causing potentiality of the present insertion variation.

3. Results and Discussion

3.1. Clinical reports for the patient

Patient belonged to Fars ethnicity of Iran and has a retinal disorder. The proband in family was a girl (IV-2, Figure 1) 20 years of age. Parents (III-1 and III-2, Figure 1) were related as first cousins. She was the only affected offspring of healthy parents who showed strabismus, horizontal nystagmus, decreased visual acuity and retinal defects. Left eye had no light perception and is unable to distinguish light from dark (NLP). In right eye vascular changes, aneurysmal telangiectasia, vascular leakage, eczema retinal, and tractional retinal detachment on the nasal side of the retina has been observed (Figure 2).

3.2. Sanger sequencing analysis of genomic amplification

Sanger sequencing validation and segregation check

![Figure 1. Family pedigree.](image1.png)

Healthy father (III-1), healthy mother (III-2), and affected daughter (IV-2) are shown in the pedigree and the inheritance of eye disease seems to be autosomal recessive in the family.

![Figure 2. Fundoscopy images.](image2.png)

Fundoscopy eyes of patient demonstrating vascular change eczema retinal, tractional retinal detachment.
were used to verify selected variant (Figure 3). Chromatograms (Figure 3) show parents are heterozygous and affected daughter is homozygous for c.1237T>G (according to the genome assembly GRCh37/hg19) in FZD4.

3.3. Variant characteristics

Type and predicted pathogenicity of the variation using some pathogenesis evaluation tools are shown in Table 1. The variant was not found in public databases including EXAC and GenmeAD or also in our homemade database, which contains more than 900 exome files.

Figure 4 shows the variant located in second exon of FZD4 transcript, which is present in amino acid 413 of Fzd4 protein. Fzd4 is a transmembrane protein with 509 amino acids, which contains two domains including cd07448 (CRD_FZ4; Cysteine-rich Wnt-binding domain of the frizzled 4 (Fz4) receptor) and cd15038 (7tmF_FZD4; class F frizzled subfamily 4, member of 7-transmembrane G protein-coupled receptors) respectively formed by amino acids 42-167 and amino acids 209-509. The varied amino acid is located in TM helix 5 of cd15038.

The secondary structure of wild-type and mutant protein analysis was done using YASARA version 15.6.21 (14). The result showed the content of Fzd4 wild type including 55.5% helix, 4.6% sheet, 7.0% turn, 31.9% coil, 0.9% 3-10 helix and 0.0% pi-helix are the same as mutant one (Figure 5).

Significantly gain of an allosteric site at R417 (Pr = 0.23, p = 0.02) and altered trans-membrane protein (Pr =

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Table 1. Location and predicted pathogenicity of the variation

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gene</th>
<th>Type</th>
<th>Mutation</th>
<th>SIFT</th>
<th>Polyphen2 HDIV</th>
<th>Polyphen2 Hvar</th>
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<tbody>
<tr>
<td>IV-2</td>
<td>FZD4</td>
<td>Missense</td>
<td>g.3873T&gt;G</td>
<td>0.001</td>
<td>1</td>
<td>0.997</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>c.1237T&gt;G</td>
<td>Damage</td>
<td>Probably</td>
<td>Probably</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cdNA.1543T&gt;G</td>
<td>(cut-off = 0.05)</td>
<td>Damaging</td>
<td>Damaging</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>p.L413V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mutation Taster</th>
<th>PredictSNP1</th>
<th>PredictSNP2</th>
<th>Proven</th>
<th>MutPred</th>
<th>Stability (I-Mutant v2.0)</th>
<th>Hydrophobicity (Peptide 2.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathogenic</td>
<td>0.99999992</td>
<td>61%</td>
<td>-2.79</td>
<td>0.72</td>
<td>Decrease</td>
<td>No difference</td>
</tr>
</tbody>
</table>

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0.01, \( p = 0.01 \) could be potential effects of the variation according to the MutPred2 molecular mechanism prediction. Peptide 2.0 analysis results showed Hydrophobic: 47.49%, Acidic: 8.57%, Basic: 10.24%, Neutral: 33.71% for both forms.

Vitreoretinopathy is a rare inherited disorder with phenotypic and genotypic variability. Although the main sign of disease is failure of peripheral retinal vascularization, it develops with variable symptoms ranging from asymptomatic vascular defects to retinal detachments with blindness. Blood vessel formation developmentally is a remarkable process, which ensures growth and function ranging from cells to the entire organism. Wnt/FRZ signaling has a central role in the development of the vascular network. To date, six genes have been reported to be a cause for vitreoretinopathy, including LRP5, FZD4, TSPAN12, NDP, ZNF408, and KIF11. LRP5, FZD4, TSPAN12, NDP proteins are members of the Wnt/Norrin signaling pathway, which plays a critical role in eye development and angiogenesis. Mostly, mutations in one of the FZD4, the TSPAN12, the ZNF408, and the KIF11 genes causes autosomal dominant, LRP5 causes autosomal dominant and recessive, and NDP causes X-linked recessive and dominant forms of vitreoretinopathy (1,2,7,15-22).

In the present study, a causative genetic mutation in an Iranian family was carried out by Whole Exome sequencing. Followed by data analysis, we identified a novel homozygous single nucleotide variation; c.1237T>G in the FZD4 gene. Healthy parents were heterozygous for the detected change. To the best of our knowledge according to the OMIM (MIM number: 133780) and review of FZD4 related literature (4,15,17,20-24) only autosomal dominant inheritance of vitreoretinopathy caused by mutations of the FZD4 gene.
have reported before. Condo et al. reported a 5-month-old baby carrying a homozygous change (p.R417Q) for which both parents harboring the same mutation heterozygously exhibited mild phenotypes, suggesting an autosomal dominant mode of inheritance with variable expressivity (15).

The result of in-silico analysis using mutation taster, Polyphen2, SIFT, MutPred, PredictSNP2, proved this variant is disease causing. In addition, the identified variant is not present in our homemade exome database, which contains 800 samples, or in public SNP databases, including dbSNP, the Exome Aggregation Consortium (ExAC), and the NHLBI GO Exome Sequencing Project (ESP). Peterson et al. showed that FZD6 dimerizes and the dimer interface of FZD6 is formed by trans-membrane α-helices four and five (25). They demonstrated that some mutations of TM5 decrease affinity between the TM4/5 peptides. These variants located in cytoplasmic domain, very close to TM5 (formed by amino acids 390-410) of Fzd4 (Figure 4) possibly can effect affinity of its dimerization. Although YASARA analysis showed, secondary structure doesn’t differ between wild-type and mutant (Figure 5), analysis of molecular mechanism changes underlying the variation by MutPred showed allosteric site at p.R417 is gained and trans-membrane protein features are altered. Notably variation of R417Q was reported before as a gain of function (formed by amino acids 390-410) of Fzd4 (Figure 4) can indirectly make a partly pathogenic effect by changes in the physicochemical characteristics of neighboring amino acids and total protein.

Finally, we conclude that the new variant c.1237T>G is highly pathogenic with a new autosomal recessive pattern of inheritance first described for vitreoretinopathy. Here by using WES technology we present the unreported inheritance -autosomal recessive- for vitreoretinopathy as the result of mutation in FZD4. The knowledge of this report; emphasizes the potency of exome sequencing acquired data in discovering new aspects of genetic diseases, and provides evidence for the autosomal recessive vitreoretinopathy caused by mutation in the FZD4 gene of note and should be considered for molecular diagnosis of vitreoretinopathy by clinicians.

Acknowledgements

We would like to express our very great appreciation to the patient and her family. We acknowledge our colleagues from Narges Genetics laboratory, especially Sahar Sedighzadeh and Jawaher Zeighami who helped us for the manuscript revision.

References


Received September 23, 2019; Revised January 7, 2020; Accepted January 17, 2020

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Released online in J-STAGE as advance publication February 4, 2020.