Sequence variations in the human PAX6 gene with aniridia in south Indian population

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Abstract

Background: Mutations in the transcription factor gene PAX6 have been shown to be the cause of the aniridia phenotype. The purpose of this study is to analyze the aniridic patients with PAX6 gene mutations in South Indian population.

Methods: Total genomic DNA was isolated from peripheral blood of twenty-eight members of six clinically diagnosed aniridia families and 60 normal healthy controls. The coding exons of the human PAX6 gene was amplified by PCR and allele specific variations were detected by single strand conformation polymorphism (SSCP) followed by automated sequencing.

Results: The sequencing results revealed novel PAX6 mutations in three patients with sporadic aniridia: c.715ins5, [c.1201delA; c.1239A>G] and c.901delA. Two previously reported nonsense mutations were also found: c.482C>A, c.830G>A. A neutral polymorphism was detected (IVS9-12C>T) at the boundary of intron 9 and exon 10. The two nonsense mutations found in the coding region of human PAX6 gene are reported for the first time in the south Indian population.

Conclusion: The genetic analysis indicates that haploinsufficiency of the PAX6 gene causes the classic aniridia phenotype. Most of the point mutations detected in our study results in premature termination of translation. Here we add three novel PAX6 gene mutations to the existing spectrum of mutations in south Indian population, which is not a well-studied ethnic group. Our study supports the hypothesis that mutation in the PAX6 gene correlates with expression of aniridia.
**Background**

Aniridia is a human congenital eye malformation with a population frequency of 1 in 60,000-100,000. Mutations in the transcription factor gene *PAX6* cause blindness [1] through a spectrum of ocular manifestations among which aniridia and the most probably foveal hypoplasia are the major signs [2-4].

The human *PAX6* gene located on chromosome 11p13, was isolated by positional cloning as a candidate gene for aniridia [5]. Point mutation in this gene will lead to premature truncation of protein [6]. Aniridia occurs due to decreased dosage of the *PAX6* gene, which controls early events in the morphogenesis of the eye and brain [7,8]. It exists in both sporadic and familial forms. One third of the aniridia cases are sporadic and two thirds are familial. The sporadic cases can be part of WAGR syndrome, which is caused by hemizygous deletions of the *PAX6* and *WT1* genes. The *PAX6* gene spans 22kb in size and consists of 14 exons and 13 introns. The translation initiation codon is in exon 4 and the termination codon is in exon 13 [7]. The human *PAX6* gene has paired box and homeobox motifs and encodes a highly conserved protein of 422 amino acids. The function of the *PAX6* protein is crucial for the development of human eye. The paired domain and the homeodomain are the two DNA binding domains, which are separated by a linker segment (LNK) and followed by a C-terminal region rich in proline, serine and threonine (PST). The presence of two DNA binding domains in *PAX6* strongly suggests that the protein functions as a transcription factor to regulate the expression of other genes during embryogenesis [9,10].

Mutations in the *PAX6* gene have been reported in a growing number of aniridia patients and patients with other ocular malformations [11, 4]. The mutations are scattered throughout the gene. The vast majority of mutations reported so far are nonsense mutations, frameshift mutations or splicing errors that are predicted to cause premature truncation of the *PAX6* protein due to haploinsufficiency [11]. Here we report five coding mutations of which
three are novel mutations in sporadic cases of aniridia in South Indian population. Our study supports the hypothesis that the mutations in the human \textit{PAX6} gene appear to correlate with classic aniridia phenotype.
Methods

Clinical Evaluation and Proband Selection.

This was done with informed consent and in accordance to the tenets of Declaration of Helsinki. Twenty-eight members of six unrelated aniridia families and 60 healthy normal controls were recruited for this study. Examination included slit lamp, gonioscopy, IOP measurement and biomicroscopy.

Mutation Screening and Sequence Analysis

Total genomic DNA was isolated by the salt precipitation method from peripheral blood [12]. The amplification of exons 4-13 to detect the PAX6 gene mutation was carried out in a 20µl reaction mixture containing 100ng of genomic DNA, 100pM of each primer, 1X PCR buffer (Promega USA) and 0.5U of Taq DNA polymerase (Promega USA). The coding region of the human PAX6 gene was amplified with previously published primers [7]. PCRs were carried out in a MJ Research thermocycler for 35 cycles, consisting of 1min at 95°C for denaturation, 1min at 58°C for primer annealing and 10min at 72°C for primer extension. Single strand conformation polymorphism analysis was carried out in 10% polyacrylamide with or without 2.5% glycerol as previously described [13]. The PCR products were sequenced to confirm the exact nucleotide change by ABI prism (Microsynth, Switzerland).

Allele Specific Clones.

The super imposed mutant PCR products were amplified, cloned into the pGEM-T vector (Promega USA). Each transformed colony contains the mutant allele or the normal allele [14]. Exon-specific PCR-SSCP was performed from the transformed colonies. Two PCR reactions were performed in parallel. The first reaction the 5’ primer is complementary to the wild type sequence and in the second reaction the 5’ primer is complementary to the mutant sequence. The elongation occurs only when primers and target sequence match completely, so only one allele of either mutant or wild type DNA is amplified [15,16]. The
plasmids were used as templates in amplification to generate PCR products for SSCP. The SSCP banding pattern was used to select allele-specific clone for sequencing (data not shown). The restriction digestion was performed for exon6 with RsaI enzyme to differentiate between mutant and normal allele and visualized on a 2.5% agarose gel.
Results

We used the SSCP technique to search for mutations in exons 4-13 of the PAX6 gene (OMIM 106210) in probands with aniridia and normal controls. The inheritance status and clinical information for each patient is given in the Table 1. The summary of our findings is given in Table 2. Altered mobility shifts detected by SSCP were confirmed by repeating two or three times. All the mutants we describe here (except two that were analysed by direct sequencing) were cloned in to the pGEM-T vector followed by allele-specific PCR to pick up the correct clone using the plasmid DNA as template because the genomic PCR gave superimposed signals. Sequencing reactions were then carried out. Although this plasmid based SSCP analysis is time consuming, it reliably allows identification of each allele. The mutant sequences are deposited in Genbank and also in the PAX6 Allelic Variant database. [Genbank Accession No. AY307164, AY289493, AY337853, AY337852, AY342394].

Novel Mutations in the PAX6 Gene

In proband 28-1 the plasmid-based clones were sequenced, revealing an insertion with duplication of five bases at position 715 in codon 118 (c.715ins5), which resulted in to a novel frameshift mutation in PAX6 gene. The pedigree and the SSCP pattern and the unusual band shift detected in exon 6 is given in Fig 2A. The phenotypic expression of aniridia is shown in Fig 1A. The insertion of 5 bases duplicates the cDNA sequence (Genbank M93650) from bases 711-715 of PAX6 gene (Fig 3). De novo change was observed at position 715 in the proband, which is a site for most common reported mutations [17-19]. The PCR product of 300bp was digested with RsaI enzyme, which resulted in a 220bp and 80bp products in normal whereas the mutant gives 220bp and 85bp (data not shown).
SSCP analysis of exon 10 in the family of proband 27-1 is shown in Fig 2B. The patient, showed abnormal band shift when compared with the unaffected family members. The plasmid-based sequencing results showed a deletion of single base at position 1201; codon 280 (c.1201delA) in PST region is shown in Fig 3. The deletion at exon 10 predicts the premature truncation at exon 12 alters the conservation of amino acids from serine at codon 280. The proband had another unique change, A>G at position 1239 (c.1239A>G), 38 bases downstream of the deletion on the same allele in exon 10 (data not shown). The two changes were identified by allele specific PCR with repeated sequencing of different clones, since the direct sequencing of genomic PCR gave superimposed signals. Two changes on one allele have been previously reported [20]. The phenotypic expression is given in Fig 1B.

In proband 10-1, an obvious bandshift on the SSCP gel was seen (Fig 2C), which on sequencing (plasmid-based) revealed the mutation c.901delA in the coding region of exon 8 at codon 180(Fig3). As a result the single adenosine residue deletion, which results in frameshift mutation generates the stop codon within the LNK region. The consequences of this mutation would be to produce a truncated protein lacking the homeobox domain. The morphology of aniridia due to deletion in the LNK region is shown in Fig 1C.

The PCR-SSCP followed by direct sequencing revealed a nucleotide substitution in proband 21-1 (Fig2D). The heterozygous transversion (C>A) was observed at position 482 (c.482C>A), which disrupts the cysteine (TGC) to stop (TGA) at codon 40 (C40X) in exon 5 of paired domain (Fig 3). As a consequent, the nonsense mutation C40X produced truncated protein lacking the LNK, homeobox and the PST region. Another nonsense mutation (W156X) was detected in proband 16-1 by SSCP gel analysis (Fig 2E), and the chromatogram revealed G>A transition at position 830 (c.830G>A) which disrupts the
tryptophan (TGG) to stop (TGA) at codon 156 in the paired domain (Fig 3). We report these nonsense mutations for the first time in south Indian population, which has been reported earlier in French population [21, 22]. The expression of aniridia is shown in Fig 1D.

**PAX6 Gene Polymorphism in Aniridia**

SSCP analysis of exon 10 in the family of proband 18-1 is shown in Fig 2F. The sequencing analysis showed an intronic change at position –12 of intron 9 (IVS9-12C>T) is shown in Fig 3. This polymorphism has been previously reported in India and Caucasian population [23,24]. Even though the mutation falls in the splice acceptor site of exon 9 it seems to be a neutral polymorphism. The unaffected parents have normal sequences in all the exons of PAX6 gene.
Discussion

Mutations of the PAX6 gene are known to cause many cases of inherited and sporadic aniridia. The PAX6 gene is clearly vital for the normal development of the eye [25]. The phenotype presumably results from heterozygous insufficiency such that if only one copy of the gene is active insufficient protein is produced to effect development of the eye. The protein products of the mutant genes could theoretically have DNA binding activity and compete with the wild type protein. However, the fact that aniridia caused by intragenic mutation is phenotypically indistinguishable from aniridia caused by deletion of entire PAX6 gene makes it likely that the mutant alleles are in fact null alleles [3,22]. The pathological mutations will be found throughout the gene including the promoter and the other regulatory regions. In these pedigrees all the mutations, if translated, result in truncated protein products. The translated proteins would be unable to carry out normal PAX6 function because functional domains are deleted hence the two DNA binding domains are important for the normal activity of the protein [6,9]. Proband 27-1 with c.1201delA, has also another change, c.1239A>G, downstream of the deletion however, its impact on transcriptional product is unknown. The downstream mutation may be less important because it is likely that the other mutation (c.1201delA) is the one responsible for aniridia. Though the two nonsense mutations C40X and W156X were previously reported in other population we found in south Indian population for the first time in aniridic pedigrees and thus it could be a recurrent mutation.

The change in the splice acceptor region of intron 9 (IVS9-12C>T) is a neutral polymorphism that has been observed before and the C>T substitution in the splice acceptor consensus sequence is not predicted to have any effect on function [26]. In addition, other studies with this change have a clear pathological mutation elsewhere in the gene [21], perhaps in one of the cis regulatory sequences.
Analysis of PAX6 mutants showed that the pathogenicity effects appear to be loss-of-function of mutation, which leads to aniridia and other variable phenotypes [22]. The mutations showed varying phenotypic severity of the disease. The proband with c.715ins5 mutation showed the presence of sclerocornea with nystagmus in both eyes. A similar phenotype (Foveal hypoplasia) was observed in probands with c.1201delA and c.482C>A. Proband 10-1 with c.901delA revealed ptosis, microcornea with dislocated cataractous lens. The marfan syndrome and ectopia lentis observed in both eyes of the proband 16-1 with c.830G>A. Even though marfan syndrome is rarely associated with aniridia [2] we observed the syndrome in the proband. The peripheral corneal pannus with bullous keratopathy and corneal ectasia was observed in IVS9-12C>T. It is worthwhile to note that all the mutations observed in this study are associated with common phenotypes.

Our data provide evidence that some of the PAX6 gene mutations identified in aniridia patients lead to disruption of PAX6 gene expression due to the premature termination and most of which are assumed to cause loss of activity of one allele [27]. The Nonsense mutations would be predicted to result in truncated proteins due to a mechanism called 'nonsense-mediated decay' which degrades mRNAs containing premature stop codons (nonsense mutations). Therefore, PAX6 mRNAs that contain nonsense mutations would be degraded and would not be translated [28]. Identifying new mutations contributes valuable information for carrier detection for specific effect mutation and genetic counseling.

Conclusions

In summary we add three novel frameshift mutations, two nonsense mutations and a polymorphism to the existing spectrum of PAX6 mutations, which showed common phenotypic expression associated with aniridia. The two nonsense mutations identified for the first time in south Indian population, which is not a well-studied ethnic group. Our genetic analysis further supports that haploinsufficiency of the PAX6 gene causes the classic aniridia.
Competing interests

None declared

Authors’ contributions

GN carried out the molecular genetic analysis. SRK, PV, and SS contributed for the clinical diagnosis of patients. PS conceived the study carried out the molecular analysis with GN and drafted the final version of the manuscript.
Acknowledgements

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References


Table. 1

Clinical and common phenotypes associated with the aniridic probands

<table>
<thead>
<tr>
<th>Proband</th>
<th>Age/ Sex</th>
<th>Best Vision</th>
<th>Refractive Error</th>
<th>Nystagmus</th>
<th>Keratopathy</th>
<th>Iris</th>
<th>Cataract</th>
<th>Glaucoma</th>
<th>Optic nerve Hypoplasia</th>
<th>Macular Hypoplasia</th>
<th>Glaucoma</th>
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<tbody>
<tr>
<td>AN-28-1</td>
<td>17yrs/F</td>
<td>6/24</td>
<td>6/24</td>
<td>+7.0</td>
<td>+7.0</td>
<td>NA</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>AN-27-1</td>
<td>8yrs/M</td>
<td>6/60</td>
<td>6/60</td>
<td>-1.0 –1.0</td>
<td>x90 –1.50</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>A</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>AN-10-1</td>
<td>13yrs/M</td>
<td>PL HM</td>
<td>NI</td>
<td>NI</td>
<td>+</td>
<td>R</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>AN-21-1</td>
<td>2mon/M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>AN-16-1</td>
<td>15yrs/M</td>
<td>6/60 HM</td>
<td>NI</td>
<td>NI</td>
<td>+</td>
<td>R</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>AN-18-1</td>
<td>30yrs/M</td>
<td>PL PL</td>
<td>NI</td>
<td>NI</td>
<td>+</td>
<td>R</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

HM – Hand Movement; PL – Perception of Light, A – Absent; R – Remnant; NA – Not Available, NI-No Improvement, 1 – Trabeculectomy, 2 –Cyclocryocoagulation, 3–Awaiting cataract surgery, 4–Cataract surgery, 5–Surgery for Retinal detachment
<table>
<thead>
<tr>
<th>Pedigree</th>
<th>Exon/Intron</th>
<th>Systematic Name</th>
<th>Codon</th>
<th>Domain</th>
<th>Type of Mutation</th>
<th>Predicted amino acid change</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN/23-1</td>
<td>9</td>
<td>c.1080C&gt;T</td>
<td>240</td>
<td>HD</td>
<td>Nonsense</td>
<td>Arginine to stop Codon</td>
<td>Neethirajan et al. 2003</td>
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<tr>
<td>AN/14-1</td>
<td>10</td>
<td>c.1180ins A</td>
<td>273</td>
<td>PST</td>
<td>frame shift</td>
<td>Premature termination</td>
<td>Neethirajan et al. 2003</td>
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<tr>
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<td>6</td>
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<td>118</td>
<td>PD</td>
<td>Frame shift due to insertion</td>
<td>Addition of one amino acid</td>
<td>Present Report</td>
</tr>
<tr>
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<td>PST</td>
<td>Deletion</td>
<td>Termination codon at Exon12</td>
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<tr>
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<td>Premature termination at exon 8</td>
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<td>c.482C&gt;A</td>
<td>40</td>
<td>PD</td>
<td>Nonsense</td>
<td>Cysteine to stop codon</td>
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</tr>
<tr>
<td>AN/16-1</td>
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<td>156</td>
<td>LNK</td>
<td>Nonsense</td>
<td>Tryptophan to stop codon</td>
<td>Present Report</td>
</tr>
<tr>
<td>AN/18-1</td>
<td>intron 9</td>
<td>IVS 9-12C&gt;T</td>
<td>--</td>
<td>HD</td>
<td>Transition</td>
<td>Neutral polymorphism</td>
<td>Present Report</td>
</tr>
</tbody>
</table>

PA- Paired domain, HD-Homeo domain, LNK- linker region, PST- proline, serine threonine region,
Legends

Fig1: Expression of aniridia with *PAX6* gene mutation

Proband 28-1, left eye (A), proband 27-1 right eye (B); proband 10-1 left eye (C); proband 16-1 right eye (D) shows typical features of aniridia.

Fig2: The pedigree and SSCP analysis of aniridia probands

Pedigree shows the affected and unaffected individual in the corresponding SSCP gel. Family members (1,2,3) Filled square (male), filled circle (female) are affected members. Unfilled square and circles are unaffected family members. N- unrelated healthy controls.

Fig3: Electropherogram showing the mutant and normal controls of *PAX6* gene

Chromatogram showing the sequence variations in *PAX6* gene is indicated by arrow. Probands 21-1 and 16-1 are direct PCR sequencing; others are plasmid based sequencing, N-Normal control, Box- duplication of sequence