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Case report

Clinical and genetic characteristics of patients with corticosterone methyloxidase deficiency type 2: Novel mutations in *CYP11B2*

SHORT TITLE: Novel mutations in CYP11B2 gene

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Abstract
Corticosterone methyloxidase deficiency type 2 is an autosomal recessive disorder presenting with salt loss and failure to thrive in early childhood. It is caused by inactivating mutations of the *CYP11B2* gene. Herein, we describe four Turkish patients from two families who have clinical and hormonal features compatible with corticosterone methyloxidase deficiency and inherit novel *CYP11B2* variants. All of the patients presented with vomiting, failure to thrive and severe dehydration except one patient who had only failure to thrive. Biochemical studies showed hyponatremia, hyperkalemia and acidosis. All patients had normal cortisol response to adrenocorticotropic hormone stimulation test and had elevated plasma renin activity with low aldosterone levels. Three patients from the same family were found a novel homozygous variant c.1175T>C (p.Leu392Pro) and a known homozygous variant c.788T>A(p.Ile263Asn) in *CYP11B2* gene. In one patient had a novel homozygous variant c.666_667delCT (p.Phe223ProfsTer35)] in the *CYP11B2* gene which caused a frame shift, forming a stop codon. Corticosterone methyleoxidase deficiency should be considered as a differential diagnosis in patients presenting with hyponatremia, hyperkalemia and growth retardation, and it should not be forgotten that this condition is life-threatening if untreated. Genetic analyses are helpful in diagnosis of the patients and their relatives. Family screening is important for an early diagnosis and treatment. In our cases, we identified novel variants that were not previously reported in the literature, and which are likely to be associated with the disease.
Keywords: aldosterone synthase deficiency, salt wasting, CYP11B2 gene, corticosterone methyl oxidase type 2, failure to thrive,

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WHAT IS ALREADY KNOWN ON THIS TOPIC?
Corticosterone methyloxidase deficiency type 2 is an autosomal recessive disorder which presents with salt loss and failure to thrive in early childhood. It is caused by inactivating mutations of the CYP11B2. To date, approximately 56 mutations have been identified in the *CYP11B2* gene.

WHAT THIS STUDY ADDS?
We describe four Turkish patients from two families who have clinical and hormonal features compatible with corticosterone methyloxydase deficiency and inherit novel *CYP11B2* mutations.

Introduction
Aldosterone is a steroid hormone synthesized by corticosterone methyloxydase (CMO) and secreted from the zona glomerulosa of the adrenal cortex. CMO catalyzes the final three steps in aldosterone synthesis (11β-hydroxylase, 18-hydroxylase, and, lastly, 18-methyloxidase), as the most important steps of aldosterone biosynthesis, which takes place only in the zona glomerulosa (1,2). In humans, two 11β-hydroxylase isoenzymes are encoded by two genes located on the long arm of chromosome 8 (3). *CYP11B1* expression is primarily controlled by adrenocorticotropic hormone (ACTH), which acts through a specific G-protein-coupled receptor to increase levels of cyclic adenosine monophosphate (cAMP). *CYP11B2* is mainly regulated by angiotensin II and potassium. The promoter region of both genes is strikingly different, underlining the fact that both genes are differently regulated on the transcriptional level, leading to two dissimilar types of the disease. Both types [CMO type 1 deficiency (OMIM 203400) and CMO type 2 deficiency (OMIM 610600)] have similar signs and symptoms but can be distinguished by laboratory testing. These conditions can be differentiated by the presence of insufficient or excessive 18-OH-corticosterone. In CMO II deficiency, despite high levels of 18 hydroxycorticosterone (18-OHB), aldosterone levels remain low or normal. These patients have a low ratio of corticosterone to 18-OHB (4). Corticosterone methyleoxidase deficiency(CMOD) type 2 is a rare disorder with unknown prevalence. The largest number of patients with CMOD type 2 has been identified subsequently in Iranian Jews from the city Isfahan (5), but the disease has been documented throughout Europe and North America (6,7).

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Corticosterone methyleoxidase deficiency can cause nausea, vomiting, dehydration, low blood pressure, extreme tiredness(fatigue) and muscle weakness, associated with hyponatremia, hyperkalemia and metabolic acidosis. Severe cases of CMOD can result in seizures and coma. Affected infants often have failure to thrive. The signs and symptoms of the disorder typically become milder or disappear by adulthood.

CASES

FAMILY □

Family □-1: A six-month-old boy was admitted with salt loss and failure to thrive and moderate dehydration. He is the first child of consanguineous parents (figure 1a), born with a birth weight of 2900 gr, length of 50 cm. Physical examination revealed growth retardation, cachectic appearance, decreased subcutaneous adipose tissue. His height and weight standard deviation scores (SDS) were -1,64 and -2.16, respectively. External genital appearance was normal. He had no hyperpigmentation. Blood pressure was normal(p95: 99/55 mmHg) (Table 1). He had hyponatremia and hyperkalemia despite elevated renin and normal aldosterone levels (Table 2). His plasma 18-OHB level and 18-OHB to aldosterone ratio were increased (Table 2). All the other adrenal hormones (17-OH progesterone, androstenedione, total testosterone, DHEA-S, cortisol) and ACTH were within normal limits. He was diagnosed as isolated aldosterone deficiency and, thus, salt and fludrocortisone treatments were initiated. In his follow-up, his electrolytes and anthropometric measurements were normalized (height SDS: -0,5, weight SDS: 0,28). Genetic analysis revealed two different homozygous variants in the *CYP11B2* **(NM_000498.3)** confirming the diagnosis of CMOD type 2. The first variant changes timin to adenin at nucleotide 788 (**c.788T>A),** resulting in an isoleucine-to-asparagine substitution at codon **263 (p.Ile263Asn)** (8). The latter variant is novel and changes timin to citosine at nucleotide 1157 (c.1157T>C), resulting in a lösine to proline substitution at codon 392 **(**p.Leu392Pro**)**.Consanguineous parents were carriers for both variants. The variants NM_000498.3:c.1175T>C(p.Leu392Pro) and NM_000498.3:c.788T>A(p.Ile263Asn) were evaluated by ACMG criteria and classified as Variant of Unknown Significance.

Family □-2: A two-year-old sibling of the first case was admitted with growth retardation. He was born at gestation week 38, with a weight of 3050 gr and length of 50 cm. From his medical records, we found out that he suffered from hyponatremia and hyperkalemia at the age of 3 months, which did not persist in his follow-up. At admission, although his electrolytes were within normal limits, his height and weight SDS were -1.99 and -2.14, respectively (Table 1). Following fludrocortisone treatment, his growth characteristics were normalized (Height SDS:0.3, Weight SDS: -0.1). Genetic analysis revealed the same variant as that of his siblings.

Family □-3: A three-month-old girl, sister of the case 1 and 2, was admitted due to poor weight gain. She was born at normal gestational age (38+5 weeks) with a birth weight of 2800 gr and length of 49 cm. Her physical examination revealed normal female external genital development, decreased subcutaneous adipose tissue. Her height and weight SDSs were -2.82 and -1.62, respectively (Table 1). Her blood pressure was 77/50 mmHg (p 95: 98/53 mmHg). She had hyponatremia, mild hyperkalemia, increased renin, and normal aldosterone levels (Table 1). Following fludrocortisone treatment adequate weight gain and height velocity were achieved and laboratory findings were normalized (Height SDS: -0.4,Weight SDS: 0.08). Genetic analysis revealed the same variant as that of her siblings.

FAMILY □

Family□-1: A three-month-old-boy was brought to our clinic due to failure to thrive and vomiting. He was the first child of non-consanguineous healthy parents (figure 1b), born with a weight of 3400 gr and length of 50 cm. On his physical examination, mild dehydration and decreased subcutaneous adipose tissue were observed. His weight was 4500 gr (SDS: -2.73), height was 58 cm (SDS: -1.66) (Table 1). Laboratory investigation showed hyponatremia, hyperkalemia, increased plasma renin activity and low serum aldosterone concentration. Adrenal steroids and ACTH levels were within normal limits (Table 2-3). A diagnosis of isolated aldosterone deficiency was established and 0.1 mg of fludrocortisone per day was initiated. A rapid weight gain, normalization of serum electrolytes, and normalization of plasma renin activity were achieved. As isolated aldosterone deficiency was the probable diagnosis, further investigations were not performed at that period of time.

In follow-up, he was reassessed at the age of 18 years and blood sample was sent for genetic analysis, which revealed a novel homozygous c.NM_000498.3:c.666_667delCT(p.F223PfsTer35) mutation in *CYP11B2* gene causing a frame shift and forming a stop codon detected by Next Generation Sequencing. This variant,which was classified as pathogenic due to ACMG criteria as it is a null variant, changes with phenylalanine 223 as the first aminoacid changed, shifting the reading frame, replacing it for a proline and terminating at position Ter35(p.Phe223ProfsTer35)(figure 2). The patient is now 18.3 years old, receiving fludrocortisone treatment, and his height and weight SDS are 0.12 and 0.59, respectively and normal for age.

Methods

Genomic DNA was extracted from peripheral blood samples of the patients. Genetic analyzes were performed by next generation sequencing (Miseq, Illumina, SanDiego) by using manufacturers instructions.

Discussion

Aldosterone deficiency is a very rare and life-threatening condition when not treated. Clinical presentation of CMOD varies by age. Since ions cross the placental barrier, despite congenital enzyme deficiency, there are no symptoms during fetal life (6). Infants with a mineralocorticoid synthesis defect may show signs of salt-wasting within the first few days or weeks of life. These findings may include vomiting, dehydration, hypovolemia, hyponatremia, hyperkalemia and metabolic acidosis. In children diagnosed in early childhood, growth failure,
nutritional problems, mild dehydration and electrolyte disturbances are observed. Miao et al reviewed 44 patients in the published literature and compared characteristics of cases with CMOD type 1and type 2. Clinical features showed no significant difference in CMOD type 1 and 2. Failure to thrive, recurrent vomiting and dehydration were most encountered symptoms in these patients (9). Although electrolyte disorder normalizes by the age of 4, growth retardation continues throughout childhood. Adults are generally asymptomatic, but they cannot tolerate severe salt loss as the normal population. They are usually recognized in family screenings.

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In the present study, age of diagnosis varied between 3 months and 2 years. Our cases have any clinical differences in previously reported CMOD cases. Our three cases presented with vomiting, severe dehydration, hyponatremia and hyperkalemia, and one case, whose brother was diagnosed previously, was asymptomatic and presented only with growth retardation. Almost all patients, as in our cases, clinically improve with aging even if clinical severity among individuals may vary widely.

Mineralocorticoid deficiency causes hyponatremia and hyperkalemia by causing excessive sodium excretion and potassium retention in renal distal tubule and cortical collection channel. In untreated infants with CMOD, serum sodium level is generally between 120-130 mmol/L and serum potassium level is between 6.0-8.5 mmol/L (10). In accordance with the literature, in our patients, initial sodium and potassium levels were between 122-126 mmol/L and 5.6-7 mmol/L, respectively. All of our cases had high plasma renin activity and normal aldosterone levels (Table 2). Plasma renin activity is significantly increased in affected infants and young children (up to 100-fold normal) but can be normal in adults.

Two types of CMOD have been identified and these syndromes have the same clinical features but differ in the profiles of secreted steroids. Type 2 deficiency can be easily diagnosed by a marked increase in the ratio of 18-OHB to aldosterone in urine or serum (usually 100-fold). This ratio does not vary by age in affected individuals despite improving clinical features. Steroid profiles of our patients are given in Table 2 and increased 18-OHB to aldosterone ratios in urine or serum are consistent with type 2. This ratio is not useful in the diagnosis of CMOD type 1 because very low levels of aldosterone make the ratio insignificant (11).

The most common disorder in patients presenting with hyponatremia, hyperkalemia and vomiting is congenital adrenal hyperplasia. Congenital adrenal hyperplasia(CAH) should be excluded because the defects of aldosterone synthesis are often seen as a part of cortisol production failure.Bizzari et al.(12) reported their ten-year-experience in infants presenting with hyponatremia and salt loss. Only 2 of 51 patients had aldosterone deficiency due to the *CYP11B2* gene defect, and the majority (37.5%) was diagnosed with CAH. The lack of ambiguous genitalia in our female patient, normal basal 17-OH progesterone levels or increased levels of renin and 18-OH progesterone differentiated our CMOD patients from CAH.

Another disorder to consider in differential diagnosis is CMOD type 1. Patients with CMOD type 1 also present with similar clinical findings. High 18-OHB levels and 18-OHB to aldosterone ratios differentiated our patients from CMOD type 1, characterized by the presence of inadequate 18-OHB.

Pseudohypoaldosteronism(PHA) is another disease to be considered in differential diagnosis. The underlying pathogenesis for PHA are unresponsive aldosterone receptor or overactive Na-Cl cotrasporter in the distal nephron.These patients do not improve with the treatment of fludrocortisone due to resistance to aldosterone (8), but in our patients with CMOD, clinical findings improved with fludrocortisone treatment.

To date, approximately 56 mutations have been identified in the *CYP11B2* gene. Primary hypoaldosteronism can be caused by different defects in *CYP11B2*, such as nonsense/missense, spli
cing, regulatory and frame shift mutations, gross deletions and complex rearrangements (data from HGMD)(13)(14). Missense/nonsense mutations have the largest proportion of these mutations (Approximately 70%) (15). However, in this case report, we found two novel and one previously reported variants in the *CYP11B2* gene.

Three siblings were homozygous for two substitution variants. The novel variant C.1175T> C (p. Leu392Pro) is known to be responsible for the reduction of enzyme activity. This variant resulted in a lösine to proline substitution at codon 392. The other variant is another substitution *CYP11B2* variant located in exon 4. This variant changes thymine-to-adenine at nucleotide 788 (c.788T>A), resulting in an isoleucine-to-asparagine substitution at codon 263. These variants were not detected in GnomAD exomes and GnomAD genomes databases.We also checked our own 2500 exome data and we could not find these variants. As the clinical picture of our patient is clearly fits with disorder, these variants were classified as "likely pathogenic". One of these two variants or both of them may be pathogenic. The other possibility is these two variants may be pathogenic in case of they are together on the same allel.

This c.788T>A(p.Ile263Asn)variant was described in another Turkish family in 2016 by Ustyol et al.(16). This pathogenic variant has so far been reported only in Turkish patients, as in our cases. p.I263N has been reported in three unrelated families, it is more likely to be pathological.

Our finding supports Turan et al.(8),which suggests an ethnic specificity of the mutation. Another point of view is that the variant p.I263N has been reported in three unrelated families so far, so it is more likely to be pathological. So far, no functional enzymatic studies of this variant have been conducted, but the clinical presentation was perfectly correlated with previous studies. The parents of our three siblings are heterozygous for the same variants. In the genetic study of case 4, a novel homozygous for two base pair frame shift mutation (c.666_667delCT) was found in *CYP11B2* and forming a stop codon. This variant changes with phenylalanine223 as the first aminoacid changed, shifting the reading frame, replacing it for a proline and terminating at position Ter35(p. Phe223ProfsTer35) and is considered to be related to the disease. However, functional analysis of genes should still be performed to determine the functional outcome of the loss in gene product.

Clinical symptoms of different severity can be observed in patients with the same mutation. Twelve patients from 8 families, reported in 1977, had the same mutation but there was a marked range in clinical severity which varied from an asymptomatic state in adulthood to acute salt-wasting crisis in infancy, detected only by biochemical profile.So researchers concluded that individual differences in the degree of severity do not reflect the allele variant(5). Instead, they indicate the effects of other genetic loci or non-genetic factors (17).

Fludrocortisone replacement is necessary to correct the deficiency. The response to mineralocorticoid replacement and salt supplementation (dramatic catch-up growth, no further diarrhea or vomiting and normalized appetite) confirmed the diagnosis. Salt wasting possibly due to IGF1 supression or reduced extracellular fluid volume and could be a factor leading to impaired growth (9).

Some studies suggest that mineralocorticoid therapy should be given for linear growth, despite normal serum electrolytes(18,19). Clinical improvement in growth rate with mineralocorticoid therapy in reported cases, who have no ion deficits but growth failure, also support this view. This condition can be explained by chronic salt wasting. Prospective studies have showed poor linear growth when both rats and humans are fed sodium deficient diets. The Na-H antiporter,

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present in many types of cell membranes, as an important mediator of cell gowth and proliferation by its action in alkalinizing the cell interior (20).
Salt-wasting improves with aging , the majority of the cases can be asymptomatic in adulthood even if not treated, with normal electrolyte levels(20,21). There are some reasons why the mineralocorticoid requirements decrease with age. Firstly, mineralocorticoid receptors are poorly expressed in the renal epithelium of newborns and this increases with age.Secondly, newborn diets (breastfeeding) had low content of sodium, and dietary sodium increased with age (9). Other reasons mentioned before including increased sodium reabsorption due to mature renal tubules and alternative pathway of mineralocorticoid biosynthesis(12).In follow-up, patients should be evaluated carefully because the need for treatment decreases with advanced aging and keeping the same dosage of fludrocortisone may lead to hypopotassemia and hypertension (18). The treatments of our patients are still being continued with reduced doses.

Conclusion

Corticosterone Methyl Oxidase Deficiency should be considered in the differential diagnosis in patients presenting with hyponatremia, hyperkalemia and growth retardation and should not be forgotten that this condition is life-threatening if not treated. Genetic analyses are beneficial for diagnosis of the patients and other relatives at the risk of salt loss and failure to thrive. Although the same variants was detected in the patients, the clinical findings may be of varying severity. Thus, family screening is important for early diagnosis and treatment.

Statement of ethics

We state that the subject and his parents have given their written informed consent to publish their case, in accordance with the Declaration of Helsinki.

Disclosure Statement

The authors have no conflicts of interest to declare.

Authorship Contributions

Concept: Hande Turan, Oya Ercan, Saadet Olcay Evliyaoğlu
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Analysis or Interpretation: Hande Turan, Saadet Olcay Evliyaoğlu, Serdar Ceylaner
Literature Search: Hande Turan, Aydilek Dağdeviren Çakır, Yavuz Özer, Gürkan Tarçın
Writing: Hande Turan, Gürkan Tarçın, Oya Ercan, Saadet Olcay Evliyaoğlu

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Table 1: Clinical features of the patients with their initial presentations, laboratory findings, genetic analyses and treatments

	Case 1	Case 2	Case 3	Case 4
Chronological Age	10,9	6,5	4,6	18,7
Gender	Male	Male	Female	Male
Age at the time of diagnosis (months)	6	24	3	3
Consaginious marriage	Yes	Yes	Yes	No
Clinical presentation	Moderate dehydratation, Failure to thrive	Growth Retardation	Poor weight gain	Failure to thrive
Weight(gr)/SDS	6,3/ -2,16	4900/ -2,14	4300/ -2,82	4500/ -2,73
Height (cm)/SDS	65/ -1,64	58.5/ -1,9	58/ -1,62	58/ -1,66
Pubertal stage at diagnosis time	1	1	1	1
Blood pressure at diagnosis time (mmHg)	70/40	80/50	77/50	80/55
Treatment	Fludrocortisone	Fludrocortisone	Fludrocortisone	Fludrocortisone
Genetic analyses	Missense mutation in CYP11B2 c.1175T>C (p.L391H) and c.788T>A (p.I263N)	Missense mutation in CYP11B2 c.1175T>C (p.L391H) and c.788T>A (p.I263N)	Missense mutation in CYP11B2 c.1175T>C (p.L391H) and c.788T>A (p.I263N)	c.666_667delCT (p.F223PfsTer35) mutation was found *CYP11B2* gene

Table 2 Laboratory findings at the time of diagnosis and Steroid levels of cases in aldosterone synthesis pathways

	Case 1	Case 2	Case 3	Case 4	Reference value
Na (Sodium) mmol/L	124	138	126	122	135-145
K (Potassium) mmol/L	6.6	4	5.6	6.8	3.5-5.2
Renin (uIU/mL)	500	265	>5500	1680	4.4-46.1
Aldosterone (ng/dL)	60	<3.7	5.6	40	5-90
ACTH (pg/mL)	24	37	30	10	6-46
Kortizol (mcg/dL)	8	19.9	15	15.7	2.8-23
Urea (mg/dL)	34	33	36	27	5-20
Creatinine (mg/dL)	0.5	0.6	0.2	0.6	0.5-1.0
Corticosterone (pmol/L)	8700	4440	6200	5760	2308-4327
18-OH corticosterone (pmol/L)	5200	7060	5200	4050	137,9- 3323
Aldosterone (pmol/L)	65.86	166	49	54	138,7-2497
18-OH corticosterone/ Aldosterone	78	42.5	106.1	75	2.3-6.0 Type 1: no sense Type 2: >10 (usually 100)
Corticosterone/ 18-OH corticosterone	1.67	0.62	1.19	1.42	

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					Type 1>40 Type 2<10

Figure 1: Pegigrees of families; 1a: Pedigree of Family □; 1b:Pedigree of Family □

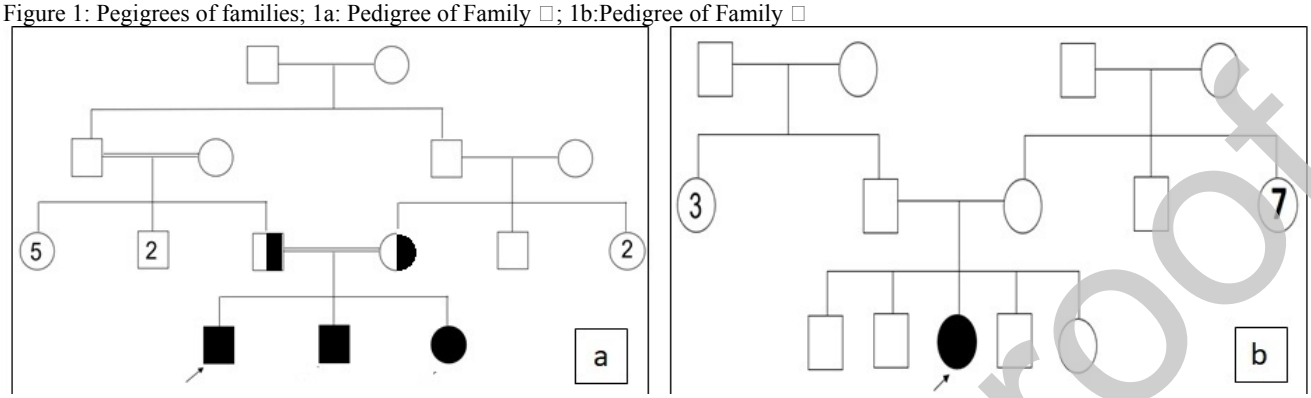
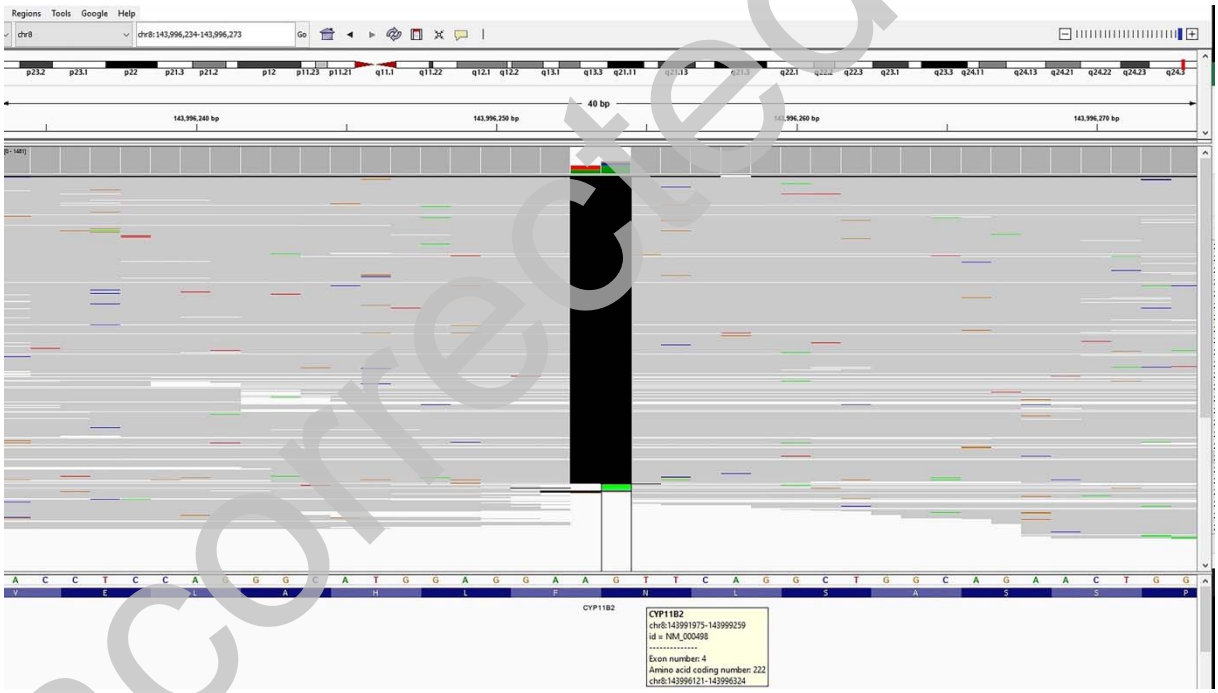


Figure 2: Image of genetic analyse of the patient "family □-1''



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