Successful Live Birth in a Chinese Woman with P450 Oxidoreductase Deficiency through Frozen-thawed Embryo Transfer

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Case report

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Abstract

Background: Congenital adrenal hyperplasia (CAH) caused by P450 oxidoreductase deficiency (PORD) in 46,XX patients is characterized by genital ambiguity, primary amenorrhea, absent or incomplete sexual maturation, infertility, skeletal malformations and so on. But few pregnancies have been reported from these female patients with PORD.

Case Description: A 29-year-old Chinese woman with PORD due to the compound heterozygous mutation (c.1370G>A/c.1196_1204del) in the P450 oxidoreductase(*POR*) gene had suffered from primary amenorrhea and infertility. She had one cancelled cycle of ovulation induction due to low serum estradiol(E_2), high progesterone(P) levels and thin endometrium，then in vitro fertilization (IVF) was recommended. At the first IVF cycle, 4 oocytes were retrieved and 4 viable embryos were cryopreserved due to thin endometrium associated with low E_2 and prematurely elevated P after ovarian stimulation, even though oral dexamethasone were used to control adrenal P overproduction at the same time. When basal P fell to <1.5ng/ml, artificial endometrial preparation and frozen embryo transfer were performed, resulting in a twin pregnancy. She delivered a healthy boy and a healthy girl by caesarean section at 37 weeks and 2 days of gestation.

Conclusions: We report the pregnancy achieved in a CAH woman caused by a compound heterozygous *POR* mutation, with primary amenorrhea and disorders of steroidogenesis. It seemed that disorders of steroidogenesis caused by PORD didn't impair the developmental potential of oocytes. IVF and frozen embryo transfer after adequate hormonal control and endometrial preparation should be an effective infertility treatment for PORD women.

Background

The enzyme P450 oxidoreductase (POR) is encoded by the *POR* gene on chromosome 7[1]. POR transfers electrons from reduced nicotinamide adenine dinucleotide phosphate (NADPH) to all microsomal (type II) cytochrome P450 enzymes, including three steroidogenic enzymes: P450c17 (17α-hydroxylase/17,20 lyase), P450c21 (21-hydroxylase), and P450aro (aromatase)[2, 3].

POR deficiency (PORD) is a rare autosomal recessive variant of congenital adrenal hyperplasia (CAH) arising from homozygous or compound heterozygous *POR* gene mutations. In 2004, mutations in *POR* gene disrupting steroid biosynthesis were firstly reported[4, 5]. Up to now over 100 cases and more than 50 different *POR* mutations have been reported(6). Patients with PORD occur mostly in neonates and children, and have a range of skeletal malformations, glucocorticoid deficiency and disorders of sexual development (DSD)[6]. Although one pair of *POR* mutations can impair all microsomal cytochrome P450 enzymes, each enzyme is affected to a different extent (depending on the locations of the *POR* gene mutations), resulting in high clinical variability of PORD, such as it has been reported that young girls or women only had incomplete pubertal development, primary amenorrhea, oligomenorrhea or infertility with or without skeletal malformations[7, 8, 9]. The clinical course of PORD in adulthood and the long-term consequence for female fertility remain unknown. In theory, the female fertility should be severely impaired by the presence of DSD and disordered steroidogenesis due to reduced activities of three steroidogenic enzymes caused by PORD[10].

We report a live birth from a woman who presented with primary amenorrhea and infertility caused by a compound heterozygote *POR* mutation.

Case

Clinical and biochemical presentation

The patient was born at term after a normal pregnancy and delivery. Her parents were nonconsanguineous and she had a healthy and fertile brother. At birth, she was healthy and had external female genitalia. At 16 years old, she presented with normal breast development, no pubic or axillary hair, normal blood pressure, but no menses, and she was evaluated for primary amenorrhea by a local gynecologist. Her karyotype was 46,XX and a pelvic ultrasound revealed the presence of 4×3×4cm ovarian cyst in the left ovary and an infantile uterus (hormonal data are not available). However the etiology of her amenorrhea remained unknown at that time. After that, she had accepted hormone replacement therapy(HRT) to establish a regular menstrual cycle but her menses didn't come when she stop HRT. When she was 29 years old and had suffered from primary infertility for three years, she was referred to treat infertility and she had a cancelled cycle of ovulation induction in the local hospital. The follicle growth and sex hormone changes during the ovulation induction were as the following : human menopausal gonadotropin(HMG)(150IU/d) were administered for 17 days from the cycle 3 of inducing menstruation after two-month oral contraception pills (OCP), and two follicles grew to 18mm and 17mm in size but serum E_2 level remained very low (<5pg/ml) with P level increasing to 25.1ng/ml and a thin endometrium (3mm). Ovulation trigger was cancelled due to the thin endometrium and the abnormal levels of E_2 and P.

Then she was referred to Reproductive Medicine Center of Sun Yat-Sen Memorial Hospital, Sun Yat-Sen University in 2014, willing to have a child. Physical examination revealed the following characteristics: a height of 158cm and weight of 60kg; Tanner scores of four for the breasts and two for axillary and pubic hair; female external genitalia; difficulty of bending the metacarpopha-langeal joints from childhood ; no other skeletal malformations were founded. No other infertility factor was identified. The evaluations for adrenal, gonadal and pituitary hormones showed that serum levels of P and 17-hydroxyprogesterone(17-OHP) were obvious high, and dehydroepiandrosterone sulfate(DHEA-S), androstenedione, free testosterone were low, as well as the other tests were within the reference ranges. **Table 1** summarized the clinical characteristics and hormonal profiles of the patient. A pelvic ultrasonography showed a hypoplastic uterus, thin endometrium and an ovarian cyst(2.9×3.0×2.8cm) in the right ovary. Bilateral integration of the adrenal glands was enlarged, as determined by a computed tomography scan.

Table 1
Clinical Characteristics and Hormonal Profiles of the study patient

	Case
Age (years)	29
Menstruation	Primary amenorrhea
Height (cm)	158
Weight (kg)	60
BMI (kg/m^2)	24.03
Blood pressure (mmHg)	118/79
Karyotype	46XX, 1qh+
Antral follicle count (n)	6
AMH (ng/ml)	2.53
FSH (IU/L)	14.80
LH (IU/L)	8.84
E_2 (pg/ml)	21
Prolactin (IU/L)	20.9
Testosterone (nmol/L)	1.21
Progesterone (ng/ml)	>40.1
17-OHP (ng/ml)	>20
Free testosterone (pg/ml)	0.19
DHEA-S (ng/ml)	223.99
Androstenedione (ng/ml)	0.82
SHBG (nmol/L)	43.39
TSH(mIU/L)	2.61
ACTH (pg/ml) 8:00 a.m	140.00
ACTH (pg/ml) 4:00 p.m	21.00
Cortisol (nmol/L) 8:00 a.m	474.39
Cortisol (nmol/L) 4:00 p.m	271.82
Aldosterone (ng/L)	115.51
Serum potassium (mmol/L)	4.23
Serum sodium (mmol/L)	141.9

Renin concentration (ng/ml/h)	2.95

BMI: body mass index; AMH: anti-Müllerian hormone; FSH: follicle-stimulating hormone; LH: luteinizing hormone; E_2: estradiol; 17-OHP: 17α-hydroxyprogesterone; DHEA-S: dehydroepiandrosterone sulfate; SHBG: sex hormone-binding globulin; TSH: thyroid stimulating hormone.

Genetic testing

The patient was suspected of having rare forms of CAH according to the clinical manifestations, imaging and laboratory tests. In order to confirm the diagnosis and find the genetic etiology, a panel of CAH candidate genes by targeted exome next-generation sequencing (NGS) were performed, including *CYP21A2*,*CYP19A1*,*CYP17A1*,*CYP11A1, HSD3B2, STAR*,*AR*,*EDNRA*,*NR5A1*,*PDE8B* and *POR* gene.

Genomic DNA were extracted from the peripheral blood leukocytes using the QIAamp DNA Blood Mini Kit (Qiagen, Hilden, Germany). The extracted DNA was segmented by DNA enzyme and purified by magnetic bead(Beckman Inc.,USA), followed by PCR amplification. DNA library was captured and purified twice by a customized Panel probe (Illumina Inc.,USA). The exon, intron-exon boundaries, the 5'and 3' flanking regions of the panel genes was sequenced by NextSeq500 (Illumina Inc.,USA).

Raw data was compared with reference sequence retrieved from the University of California at Santa Cruz Genome Browser (http://genome.ucsc.edu) (UCSC,hg19) by the BWA algorithm and annotated using the method reported by Zhang[11]. The HGVS (www.hgvs.org/mutnomen/) guidelines for describing sequence variations and numbering were used, with +1 corresponding to the A of the ATG translation initiation codon of the GenBank cDNA sequence and the amino acid sequences. All variants were classified according to the American College of Medical Genetics and Genomics (ACMG) 2015 classification[12]: pathogenic, likely pathogenic, uncertain significance, likely benign and benign. Sanger sequenced was performed in suspected variations.

The results showed that no mutation and copy number variation were found in *CYP21A2*,*CYP19A1*,*CYP17A1*,*CYP11B1*,*HSD3B2*,*AR*,*EDNRA*,*NR5A1*,*PDE8B* and *STAR*, but a compound heterozygous mutation was found in *POR* gene(NM_000941.2): c.1370G>A (p.Arg457His,rs28931608,) and c.1196_1204del (p.Pro399_Glu401del) [**Figure 1**]. The sequencing results of her parents showed that her father was a heterozygous carrier for c.1370G>A and her mother was a heterozygous carrier for c.1196_1204del. The c.1370G>A had been found in some PORD patients(HGMD:CM040474), which are common in Japanese and Chinese patients [4,6,8,13,14]. The mutation of c.1370G>A in *POR* gene leads to a conversion of arginine at amino acid position 457 to histidine (R457H) which supports only 3% of 17-hydroxylase activity, no detectable 17,20 lyase activity [4,5], and only 1% of aromatase activity [15] The c.1196_1204del mutation in *POR* gene was firstly reported in two unrelated Turkish PORD patients(HGMD ID:CD117091) and cause a loss of three amino acid p.Pro399_Glu401del (P399_E401del)(16) . In comparison to wild-type POR, this P399_E401del mutation was found to decrease catalytic efficiency of 21-hydroxylase by 68%, 17α-hydroxylase and 17,20 lyase by 76% and 69%, and aromatase by 85%[16,17]. The variants c.1370G>A and c.1196_1204del were classified by pathogenic and likely pathogenic respectively according to ACMG.

Fertility treatment

According the clinical presentation, the results of biochemical tests and genetic testing the patient was diagnosed as PORD. Then she was given HRT composed of estradiol and progesterone (Femoston, Abbott Biologicals B.V, Netherland), combined with oral dexamethasone (0.375mg/d) for two months. After the therapy her basal serum P and 17-OHP levels fell to normal levels(0.35ng/ml and 0.23ng/ml respectively) with disappearance of the ovarian cyst. According to our several successful cases with atypical CAH caused by 17α-hydroxylase deficiency through frozen embryo transfer after IVF and the pregnant case with 17α-hydroxylase deficiency published in 2016[18] who showed similar changes of sex hormones and inadequate endometrial development during ovarian stimulation, IVF management was recommended. Oral dexamethasone(0.375 mg/d) was maintained during all treatment phases.

Ovarian stimulation for IVF

We performed a long GnRH agonist protocol with down regulation using a single dose of 1.3mg long-acting triptorelin and ovarian stimulation with 225IU/d of recombinant FSHα(rFSH) and 75IU/d HMG. When four follicles reached to 20 mm, 19mm,16mm and 15mm in diameter, 10,000IU of human chorionic gonadotropin(HCG) was administered for triggering the maturation of oocytes on Day 21 of stimulation. On the triggering day serum levels of E_2 and P were 33pg/ml and 2.3ng/ml respectively with a thin endometrium (4mm), which showed less disorder comparing with them in the cycle of ovulation induction without oral dexamethasone and GnRH agonist down regulation. Then 4 oocytes were retrieved 36 hours after HCG triggering and 4 cleavage embryos were available and cryopreserved. The details were shown in **Table 2**.

Table 2
Ovarian stimulation for IVF and the changes of hormones

Cycle day	-21	0	6	11	17	23	26
dexamethasone	0.375mg/d						
long-acting triptorelin(mg)	1.3	/	/	/	/	/	/
rFSH(IU/d)	/	225	150	75	75	/	/
HMG(IU/d)	/	/	75	150	225	300	/
HCG(IU)	/	/	/	/	/	/	10000
Follicles (mm) and (number)	5(4)	4(4),3.5(3)	6.5(2),4(4)	9(2),7(2), 5(3)	11(2),9(2), 5(3)	17(1),15(1), 10(2)	22(1),17(2), 12(1)
Endometrial thickness(mm)	5.0	2.3	2.8	4	4.1	5.0	5.0
FSH (IU/L)	14.5	2.8	14.8	13.1	14.7	15.7	16.4
LH (IU/L)	5.6	3.0	1.6	1.1	0.8	0.6	0.6
E_2 (pg/ml)	20	20	<20	<20	<20	30	33
P (ng/ml)	0.3	0.2	0.1	0.2	0.3	1.6	2.3

rFSH: recombinant FSHα; HMG: human menopausal gonadotropin; HCG: human chorionic gonadotrophin; FSH: follicle-stimulating hormone; LH: luteinizing hormone; E_2: estradiol; P: progesterone

Pregnancy after frozen-thawed embryo transfer with artificial endometrial preparation

The patient's menses came 17 days after oocyte retrieval. On cycle 3 serum P level was 0.6 ng/ml and artificial endometrial preparation was started with oral estradiol valerate (4mg/d). When endometrial thickness reached 10.4mm, progesterone in oil(60mg/d) was administered by intramuscular injection, and 3 days later, two frozen-thawed embryos were transferred. After embryo transfer, oral dexamethasone wasn't given any longer considering the patient had never presented with adrenal insufficiency before. A twin pregnancy was attained and estradiol and progesterone was maintained during the first trimester of pregnancy. The pregnancy proceeded uneventfully, with the regular monitor in the department of Endocrinology and Obstetrics. A healthy boy and a healthy girl were delivered by caesarean section after 37 weeks and 2 days of gestation, weighing 2.5kg and 2.3kg respectively. No perinatal problems were observed, and the puerperium was uneventful. During the pregnancy and post-partum period, she had not presented with adrenal insufficiency and no need for glucocorticoids replacement. She remained amenorrhea one year after delivery and has been accepting HRT until now.

Discussion

A recently published review showed that PORD is a complex disorder with many possible mutations affecting a large number of enzymes and the most common mutations were R457H(25%) and A287P(24%) in 180 individual POR mutations from 90 patients[6]. Several phenotypic features were very common in PORD women but occurred across a range of mutations, including of high serum concentrations of P (100%), pregnenolone (100%), 17OHP (96%), corticosterone (83%) and deoxycorticosterone (DOC)(70%), DSD(78%), ovarian cysts(39%), skeletal malformations(84%), and adrenal insufficiency(78%) with most of mild cases[6]. For late-onset PORD primary amenorrhea/oligomenorrhea or infertility could be the main clinical manifestation [7, 8, 9], but little is known about the optimal way to investigate and treat patients with adult-onset PORD. Our case presented with features of high P and 17OHP, primary amenorrhea, ovarian cyst, minor skeletal malformation and no obvious sign of adrenal insufficiency. A compound heterozygotes for c.1370G > A (R457H) and c.1196_1204del (P339_E401del) were found which had been confirmed to reduce activities of P450c17, P450c21, and P450aro[4, 5, 15–17].

As so far the clinical course and of PORD in adulthood and the long-term consequence for fertility remain unknown and until now no spontaneous pregnancy in PORD female patients has been reported. This is a first live birth report by assisted reproduction treatment in a Chinese PORD women with a compound heterozygous mutation of c.1370G > A and c.1196_1204del in *POR* gene that led to primary amenorrhea and primary infertility. In a recent published paper from France, PORD was biologically and genetically confirmed in five adult women with chronically elevated serum P who were referred for oligo-/amenorrhea and/or infertility, and two of these five PORD women were reported to obtain successful live births by assisted reproductive treatment[9]. However comparing with our case, the two patients had milder clinical phenotypes with oligomenorrhea and infertility, and two different compound heterozygous mutations of c.1249-1G >C/ c.1324C >T and c.1825C >T/ c.1859G >C in *POR* gene [9]. Our case provided additional information of effective infertility treatment in PORD women with different ethnicity, clinical phenotype and *POR* gene mutation. The impairment of reproductive capacity in PORD women may be mainly explained by the effects of estradiol deficiency and progesterone excess from both adrenal and gonad, accentuated by ovarian stimulation, on endometrial development. These conditions occurred in our case. During the ovulation induction with HMG she presented with normal follicular growth but higher serum P and thin endometrium with undetectable serum E_2, which means that ovarian stimulation and follicular development increase the P overproduction from ovary.

IVF can be used to segment ovarian stimulation and embryo transfer to avoid the negative effect of high P and low E_2 on endometrial receptivity by freezing all available embryos. Freeze-all policy have been successfully used in women undergoing IVF under various conditions such as the premature elevation of serum P after conventional ovarian simulation[19, 20], luteal phase stimulation[20, 21] and progestin-primed ovarian stimulation protocol and so on[20, 22]. Therefore, it suggests that high P level during the period of follicular growth may not impair the developmental capacity of the oocyte and the effect of high P on endometrium can be overcome with cryopreservation and frozen-thawed embryo transfer(FET). As for low estradiol, previous reports showed estrogen may not play a key role in folliculogenesis and follicular development in vivo and in vitro[23, 24], but gonadotrophins play a vital role in the growth and maturation of follicles[25]. In the successful pregnancies in CAH women caused by 17-hydroxylase deficiency and steroidogenic acute regulatory protein (StAR) mutations, the patients presented with primary amenorrhea and absent or incomplete sexual

maturation[18, 26]. The authors both reported that during their IVF treatment, endogenous estrogen level was very low but follicles grew normally after ovarian stimulation and normal embryos and pregnancies were obtained[18, 26], just as our case reported. So we suggest that the disorders of gonadal steroidogenesis caused by rare forms of CAH may have little effect on the follicular growth and the developmental capacity of the oocytes. Although only few cases have been reported to be successful pregnancies, it may be an effective way to help them have their own children, through IVF and FET after using exogenous estrogen for endometrial preparation and corticoids or combined with GnRH agonist when necessary to suppress the overproduction of progesterone from adrenal and gonad. Of course, a multidisciplinary team including reproductive endocrinologist, internal endocrinologist, obstetrician and geneticist is needed for these women to get through the pregnancy and delivery[27].

Conclusions

In conclusion, It is a second report of successful pregnancy in a PORD patient who had primary amenorrhea and different *POR* mutation. For this rare form of CAH, it seemed that disorders of steroidogenesis caused by PORD didn't impair the developmental potential of oocytes. The successful pregnancy could be obtained through IVF and FET after adequate hormonal control and endometrial preparation and these should be confirmed by more clinical evidence in the future.

Declarations

Acknowledgments

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Authors' contributions

PP and LZ- wrote the manuscript and edited it in all its revisions, collected the clinical and laboratory data, performed the genetic analysis and took part in discussions regarding the results. XC and JH- participated in managing the whole infertility treatment of the case, retrieved the data, proof read the paper and took part in discussions regarding the results. DY-proof read the paper and took part in discussions regarding the results. YL- designed and performed the study, oversaw the data interpretation and critically revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The data used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was approved by the ethical committee of Sun Yat-sen Memorial Hospital, Sun Yat-sen University (SYSEC-KY-KS-2019-052).

Consent for publication

Not applicable.

Competing interests

The authors have nothing to declare.

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Figures

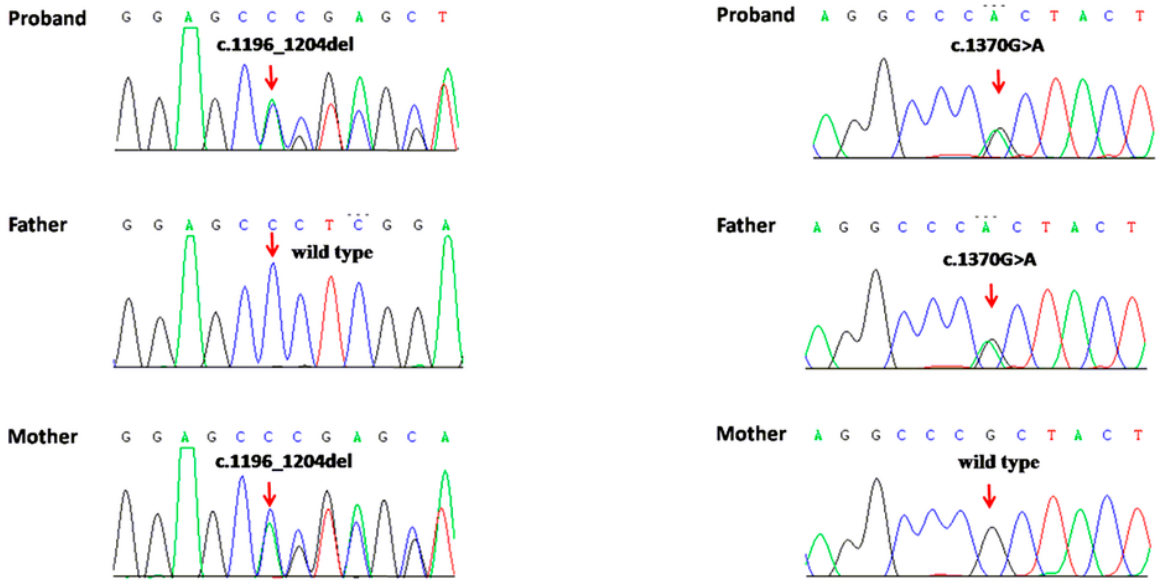

Figure 1

The Sequencing chromatogram of the mutations from the proband patient and her parents.