The Application of Clinical Genetics

Pena–Shokeir syndrome: current management strategies and palliative care

Sumaiya Adam1
Melantha Coetzee2
Engela Magdalena Honey3

1Department of Obstetrics and Gynaecology, Steve Biko Academic Hospital, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa; 2Division of Neonatology, Department of Pediatrics and Child Health, Steve Biko Academic Hospital, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa; 3Department of Biochemistry, Genetics and Microbiology, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria, South Africa

Abstract: Pena–Shokeir syndrome (PSS) type 1, also known as fetal akinesia deformation sequence, is a rare genetic syndrome that almost always results in intrauterine or early neonatal death. It is characterized by markedly decreased fetal movements, intrauterine growth restriction, joint contractures, short umbilical cord, and features of pulmonary hypoplasia. Antenatal diagnosis can be difficult. Ultrasound features are varied and may overlap with those of Trisomy 18. The poor prognosis of PSS is due to pulmonary hypoplasia, which is an important feature that distinguishes PSS from arthrogryposis multiplex congenital without pulmonary hypoplasia, which has a better prognosis. If diagnosed in the antenatal period, a late termination of pregnancy can be considered following ethical discussion (if the law allows). In most cases, a diagnosis is only made in the neonatal period. Parents of a baby affected with PSS require detailed counseling that includes information on the imprecise recurrence risks and a plan for subsequent pregnancies.

Keywords: fetal akinesia deformation sequence, ultrasound, comfort care

Introduction

Pena–Shokeir syndrome (PSS) is a lethal form of multiple congenital contractures with autosomal recessive inheritance implicated in 50% of cases. However, heterogeneity makes recurrence risk calculations difficult.

Two types of PSS have been described:

- Type 1: It is a fetal akinesia/hypokinesia sequence that is characterized by multiple joint contractures, facial anomalies, and pulmonary hypoplasia. It has a prevalence of <1/1,000,000 births, with an autosomal recessive mode of inheritance. About 100 cases have been described in the literature, with about 30% of fetuses dying in utero, and the vast majority of neonates succumbing in the early neonatal period due to pulmonary hypoplasia.

- Type 2: It is also known as cerebro-oculo-facio-skeletal (COFS) syndrome. It is a rapidly progressive neurological disorder resulting in brain atrophy, characterized by intracerebral calcifications, cataracts, microcornea, optic atrophy, progressive joint contractures, and growth failure. It is a very rare autosomal recessive disorder caused by mutations in ERCC6/CSB, although mutations in ERCC1, ERCC2, and ERCC5 have been linked to some cases. Death usually occurs by 5 years of age.

Further discussion in this review will be restricted to PSS type 1.
Pathogenesis

PSS is a heterogeneous group of disorders characterized by a decrease or absence of intrauterine fetal movement. It is also called “fetal akinesia deformation sequence” (FADS). Arthrogryposis multiplex congenital (AMC), multiple pterygium syndrome (MPS), and lethal congenital contracture syndromes are conditions that have overlapping phenotypes and etiologies. The clinical phenotype initially described by Pena and Shokeir (1974, 1976) included camptodactyly; multiple contractures; facial anomalies consisting of a high nasal bridge, micrognathia, and a cleft palate; and pulmonary hypoplasia resulting in death in utero or shortly thereafter.\(^4\)\(^5\) The initial description included multiple consanguineous families, and an autosomal recessive inheritance pattern was suggested. Sporadic and familial occurrences have been described subsequently depending on the underlying etiology. This has led to the identification of up to 30 different subgroups.\(^6\)\(^7\) X-linked dominant inheritance has also been suggested.\(^8\)\(^9\)

The underlying etiology is dysfunction of the neuromuscular system resulting in decreased intrauterine fetal movements. It includes the brain and spinal cord, motor neuron, neuromuscular junction, and neurotransmitter defects.\(^6\) Muscle myopathic changes leading to the failure of development of normal mature muscle, including dystrophies and dysplasias, have also been implicated.\(^7\) Other causes include connective tissue abnormalities such as chondrodysplasias, conditions associated with joint limitation and laxity, as well as restricted skin (restrictive dermopathy).\(^7\) Environmental causes include antibodies to neurotransmitters and fetal acetylcholine receptor (AChR), as well as reduced intrauterine space such as that seen in multiple births, oligohydramnios, and uterine abnormalities. The earlier the effect, the more severe the phenotype. Maternal illness and drug use, as well as fetal ischemia, have also been described in isolated cases.\(^6\)

A possible relation to maternal myasthenia gravis was described in 1994. Maternal anti-AChR antibody titers were increased in the absence of any clinical symptoms of myasthenia gravis in the mothers. In these cases, the recurrence risk was very high and all subsequent pregnancies were affected.\(^10\)\(^11\) Other case reports have confirmed this and have suggested that the antibodies were different from those usually associated with myasthenia gravis. Adult anti-AChR antibodies replace fetal anti-AChR by 33 weeks of gestation. This explains why the fetus is markedly affected compared with their mothers.\(^10\)\(^12\)

Genetics

Advances in molecular genetic research have improved our knowledge of the genetic causes of PSS and suggest that many cases are at the severe end of the spectrum of other recognized conditions involving the neuromuscular system. Alternatively, autosomal dominant neuromuscular conditions can present with PSS when the gene defect is in the homozygous state.\(^7\)

Variations in the genes involved in the neuromuscular pathways for fetal movement cause PSS. Variations in RAPSN (Online Mendelian Inheritance in Man [OMIM] 601592), DOK7 (OMIM 610285), and MUSK (OMIM 601296) are also implicated in congenital myasthenic syndrome (CMS), but have been identified as some of the major genes involved in the etiology of PSS through deficient interaction in the neuromuscular junction.

RAPSN

RAPSN is located on chromosome 11p11.2. It codes for a postsynaptic protein (rapsyn) that links the AChR to the agrin-binding dystrophin-associated glycoprotein complex and stabilizes the AChR at the neuromuscular junction.\(^13\) Homozygosity or compound heterozygosity for mutations results in AChR deficiency and FADS or CMS. Michalk et al reported the case of a brother and a sister in a non-consanguineous Pakistani family.\(^14\) Both siblings were born with severe respiratory problems, contractures, and subtle dysmorphisms. The male infant died at 10 months due to respiratory failure. He also had cryptorchidism. The female infant had a cleft palate but was still alive at 10 months. They both had compound heterozygous mutations of c.416T→C/c.566C→T. Vogt et al identified a homozygous splice-site mutation of c.1177_1178delAA in a consanguineous family (monozygotic twin males and a female).\(^15\) All the affected fetuses were terminated and showed FADS upon examination after delivery. A homozygous c.484G>A (p.Glu162Lys) variant was identified by Winters et al in consanguineous parents in their fifth pregnancy. Their fourth pregnancy was also affected, but they refused testing during the previous pregnancy.\(^16\)

DOK7

DOK7 is involved in AChR clustering in synaptogenesis and binds with and phosphorylates MUSK. It is located at 4p16.3. In a consanguineous family with three affected children, Vogt et al identified a homozygous splice-site mutation (IVS3+1G>T or c.331+1G>T) in DOK7 causing lethal FADS.\(^17\) DOK7 variations are usually associated with CMS and with limb girdle weakness.\(^18\) This model illustrates that a partial loss of DOK7 function causes CMS but a complete loss of DOK7 function causes a lethal FADS phenotype.
MUSK

MUSK is located at 9q31.3. It forms and maintains the neuromuscular junction. Muscle cells produce and express AChR. Agrin, a proteoglycan released by motor nerves, binds to LRP4 and activates MUSK, which then signals via DOK7 and RAPSN to stabilize the AChR.19 Wilbe et al reported that a complete loss of MUSK causes autosomal recessive FADS.20 A homozygous frameshift mutation (c.40dupA) in exon 1 leading to a premature stop codon was found in a non-consanguineous Swedish family with five affected fetuses. The mutation was identified through whole-exome sequencing followed by Sanger sequencing. In the same year, Tan-Sindhunata et al identified a homozygous Dutch family with FADS.21

Other variations in the genes involved in the neuromuscular pathways for fetal movement can cause PSS. There are, however, a large percentage of unknown cases. Next-generation sequencing (NGS) technologies will improve the diagnosis and enable accurate prognosis prediction, recurrence risk estimation, as well as genetic counseling. NGS panels are being developed to investigate heterogeneous conditions such as PSS where variants in different genes are causative. Whole-exome sequencing earlier in the diagnostic process will be a useful tool to identify new genes not previously described.

Details on the anatomical areas involved, genes (Mendelian Inheritance in Man [MIM] number), inheritance pattern, phenotype (MIM number), and references of all known gene variations associated with FADS are given in Table 1.

Antenatal diagnosis

It is not easy to diagnose PSS as it has a variable phenotype and shares many ultrasonographic features with Trisomy 18 and other syndromes (Table 2).6

The presence of pulmonary hypoplasia is helpful in distinguishing PSS from AMC which has a better prognosis. Invasive testing for chromosomal analysis is advised when a diagnosis is suspected. If the karyotype is normal, and other conditions have been excluded, a presumptive diagnosis of PSS can be made.

Antenatal diagnosis of PSS can be made on ultrasound as early as 12 weeks of gestation if decreased intrauterine fetal movements, edema, and fixed limb posturing are observed. Polyhydramnios is invariably present in the latter half of pregnancy, with a proportion of fetuses developing hydrops fetalis, and becoming more prone to death in utero.

Antenatal ultrasonographic features include decreased fetal movements, intrauterine growth restriction, joint contractures, short umbilical cord, and features of pulmonary hypoplasia. Limbs may be in contraction or extension – knees are usually extended and elbows are flexed. Feet may have severe equinovarus or rocker bottom deformity. Facial features include hypertelorism, low-set ears, depressed tip of the nose, and micrognathia. A disproportionally large head in relation to the body is usually described.4 Three-dimensional ultrasound and fetal magnetic resonance imaging (MRI) may be considered as an adjunct to fetal imaging.64

Obstetric management

The ideal way to convey bad news to a patient remains controversial. Adequate counseling often requires multiple consultations with various health care professionals, including maternal and fetal specialists, geneticists, and neonatologists. The consultation process should include the patient’s partner or family who can assist with the decision-making process, as well as offering emotional support. Counseling should include information on the diagnosis and prognosis (antenatal, intrapartum, postnatal, and long term), and information regarding future pregnancies.55,66

The fetus diagnosed with PSS has a poor prognosis. Close to term, the obstetric management would usually continue to be supportive, with delivery via cesarean section reserved for obstetric indications. The patient should be counseled that no intrapartum fetal heart rate monitoring to be carried out due to the poor prognosis, and that the neonate will be evaluated after birth by a neonatologist and geneticist. Palliative care following secondary postnatal assessment should be discussed with the patient. Due to the dismal prognosis of PSS, late termination of pregnancy can be offered as a management option in countries/states where it is legal and acceptable.

Postnatal care

PSS must be differentiated from other causes of FADS as the level of care offered after delivery may be dependent on the expected prognosis. If the diagnosis of PSS is made during the antenatal period, the parents may choose to terminate the pregnancy. Alternatively, the patient may opt for comfort care following secondary postnatal assessment should be discussed with the patient. Due to the dismal prognosis of PSS, late termination of pregnancy can be offered as a management option in countries/states where it is legal and acceptable.
Table 1 Summary of the genetic causes of Pena–Shokeir phenotype

<table>
<thead>
<tr>
<th>Anatomical localization</th>
<th>Gene (MIM number)</th>
<th>Gene action</th>
<th>Inheritance pattern</th>
<th>Phenotype</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>TUBB2B (612850)</td>
<td>Beta form of tubulin – major component of microtubules</td>
<td>AD</td>
<td>FADS with MLE</td>
<td>Laquerriere et al (2016)(^2)</td>
</tr>
<tr>
<td></td>
<td>PIP5K1C (606102)</td>
<td>Production of phosphatidylinositol-4,5-biphosphate</td>
<td>AR</td>
<td>LCCS3</td>
<td>Narkis et al (2007)(^2)</td>
</tr>
<tr>
<td>Peripheral nerves</td>
<td>UBE1 (314370)</td>
<td>Ubiquitin-activating enzyme 1</td>
<td>X-linked</td>
<td>X-L SMA</td>
<td>Ramser et al (2008)(^2)</td>
</tr>
<tr>
<td></td>
<td>MPZ (159440)</td>
<td>Myelin protein zero gene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CHRNBI (100710)</td>
<td>AChR β-subunit</td>
<td>AR</td>
<td>LMPS, FADS</td>
<td>Michalk et al (2008)(^2)</td>
</tr>
<tr>
<td></td>
<td>CHRND (100720)</td>
<td>AChR δ-subunit</td>
<td>AR</td>
<td>LMPS, FADS</td>
<td>Michalk et al (2008)(^2)</td>
</tr>
<tr>
<td></td>
<td>DOK7 (610285)</td>
<td>Synaptogenesis through interaction with MUSK</td>
<td>AR</td>
<td>FADS/CMS, familial limb-girdle myasthenia</td>
<td>Vogt et al (2009)(^2)</td>
</tr>
<tr>
<td></td>
<td>SYNE1 (608441)</td>
<td>Synaptic nuclear envelope protein-I</td>
<td>AR</td>
<td>FADS, myogenic AMC</td>
<td>Attali et al (2009)(^2)</td>
</tr>
<tr>
<td></td>
<td>ECEL1 (605896)</td>
<td>Endothelin-converting enzyme-like 1</td>
<td>AR</td>
<td>AMC/DA type 5</td>
<td>Dohrn et al (2015)(^2)</td>
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<thead>
<tr>
<th>Anatomical localization</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MYBPC1 (160794)</td>
<td>Myosin-binding protein C1, skeletal muscle slow type</td>
<td>AD/AR</td>
<td>DA1/LCCS type 4</td>
<td>Gurnett et al (2010)45</td>
</tr>
<tr>
<td></td>
<td>DMPK (605377)</td>
<td>Dystrophia myotonica protein kinase</td>
<td>AD</td>
<td>FADS</td>
<td>Winters et al (2017)16</td>
</tr>
<tr>
<td></td>
<td>DMPK (160900)</td>
<td>Dystrophia myotonica protein kinase</td>
<td>AD</td>
<td>MD/FADS</td>
<td></td>
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<tr>
<td></td>
<td>MTM1 (300415)</td>
<td>Myotubularin</td>
<td>X-linked</td>
<td>FADS</td>
<td>Winters et al (2017)16</td>
</tr>
<tr>
<td></td>
<td>TPM2 (190990)</td>
<td>Tropomyosin 2</td>
<td>AR/AD</td>
<td>MPS Escobar variant, DA type 1/2B</td>
<td>Winters et al (2017)16</td>
</tr>
<tr>
<td></td>
<td>TNNI2 (191042)</td>
<td>Troponin 1 – fast twitch skeletal muscle</td>
<td>AD</td>
<td>DA type 1, DA type 2B</td>
<td>Winters et al (2017)16</td>
</tr>
<tr>
<td></td>
<td>TNNT3 (600692)</td>
<td>Troponin 3 – fast skeletal muscle</td>
<td>AD</td>
<td>DA type 1, DA type 2B</td>
<td>Winters et al (2017)16</td>
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<tr>
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<th>Gene action</th>
<th>Inheritance pattern</th>
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<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chanelopathy</td>
<td>SCN4A (603967)</td>
<td>Sodium channel, voltage-gated type IV, alpha</td>
<td>AR</td>
<td>FADS/CM</td>
<td>Winters et al (2017)16</td>
</tr>
<tr>
<td></td>
<td>NALCN (611549)</td>
<td>Sodium leak channel, nonselective</td>
<td>AD</td>
<td>CLIFAHDD</td>
<td>Winters et al (2017)16</td>
</tr>
<tr>
<td></td>
<td>GBE1 (607839)</td>
<td>Glycogen branching enzyme</td>
<td>AR</td>
<td>GSD IV/FADS</td>
<td>Ravenscroft et al (2013)19</td>
</tr>
<tr>
<td></td>
<td>ZMPSTE24 (606480)</td>
<td>Zinc metalloprotease involved in the processing of farnesylated proteins</td>
<td>AR</td>
<td>RD</td>
<td>Smigiel et al (2010)62</td>
</tr>
<tr>
<td>Immunological causes</td>
<td>FGR2 (176943)</td>
<td>Fibroblast growth factor receptor 2</td>
<td>AD</td>
<td>Pfeiffer syndrome/LMPS</td>
<td>Baynam et al (2008)63</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
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</tr>
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</table>

Abbreviations: MIM, Mendelian Inheritance in Man; AD, autosomal dominant; FADS, fetal akinesia deformation sequence; MLe, microlissencephaly; AR, autosomal recessive; SMA, spinal muscular atrophy; LCCS, lethal congenital contracture syndrome; AMC, arthrogryposis multiplex congenital; LAAHDD, lethal arthrogryposis with anterior horn cell disease; AAHD, arthrogryposis with anterior horn cell disease; X-L SMA, X-linked spinal muscular atrophy (301830); CHN, congenital hypomyelination neuropathy; AChR, acetylcholine receptor; LMPS, lethal multiple pterygium syndrome; NMj, neuromuscular junction; CMS, congenital myasthenic syndrome; DA, distal arthrogryposis; TPS, trisomy-pseudocamptodactyly syndrome; NM, nemalin myopathy; CCD, central core disease; SMAED, autosomal dominant spinal muscular atrophy with lower extremity predominance; CNM, centronuclear myopathy; MD, myotonic dystrophy; MMT, myotubular myopathy; MPS, multiple pterygium syndrome; CM, congenital myopathy; CLIFAHDD, congenital contractures of the limbs and face with hypotonia and developmental delay; GSD, glycogen storage disease; X-D PDHA, X-linked dominant pyruvate dehydrogenase E1-alpha deficiency; CDG II, Congenital disorder of glycosylation type II; IPEX, immune dysregulation, polyendocrinopathy, enteropathy, X-linked syndrome; RD, rare disease; FADS, fetal akinesia deformation sequence; AMC, arthrogryposis multiplex congenital; DA, distal arthrogryposis.

Table 2 Differential diagnosis of conditions with markedly decreased intrauterine fetal movements6

- Adenylosuccinate lyase deficiency
- Cerebro-oculo-facial syndrome (Pena–Shokeir type 2)
- Congenital myopathies
- Congenital myasthenia gravis
- Fetal akinesia deformation sequence (Pena–Shokeir type 1)
- Fukuyama muscular dystrophy
- Glycosylation type IA deficiency
- Infantile Pick’s disease
- Lethal Larsen syndrome
- Lethal pterygium syndrome
- Lissencephaly III
- Maternal antibodies to fetal acetylcholine receptor
- Mucopolysaccharidosis III
- Neu–Laxova syndrome
- Progressive encephalopathy, edema, hypsarrhythmia, optic atrophy syndrome
- Phosphofructokinase deficiency (glycogenosis VII)
- Potter syndrome
- Restrictive dermopathy
- Trisomy 18
  - Walker–Warburg syndrome
may include camptodactyly, absent palmar creases, rocker bottom feet, talipes equinovarus, cryptorchidism, short neck, small mouth, and a cleft palate. The craniofacial abnormalities, skeletal abnormalities, and pulmonary hypoplasia are all secondary to decreased or absent fetal movement in utero. The differential diagnosis includes Trisomy 18, MPS, and COFS. A normal karyotype, and the absence of ptterygia causing flexion contractures, microphthalmia, and microcephaly allow differentiation of PSS from Trisomy 18, MPS, and COFS. 71,72

Despite the poor survival rate, most patients with PSS receive complete resuscitation after delivery and full postnatal care, including antimicrobials, inotropes/vasopressors, and repeated cardiopulmonary resuscitation until death. 69 There are, however, cases describing redirection of care from life-sustaining treatment (invasive ventilation) to comfort care after discussion with the parents. 72,73

If full resuscitative efforts are agreed upon, the resuscitation team must anticipate that the newborn will have respiratory distress secondary to pulmonary hypoplasia and be prepared for a difficult intubation 74 due to edema of the head,75,76 a short neck,76 and micrognathia.75,76 Various airway devices must be available, including a face mask, oral and nasal airways, laryngeal mask airways, and endotracheal tubes with the addition of a fiber optic or video laryngoscope, if possible. 2

No specific treatment is available for those with PSS, and management is largely supportive. 77 A karyotype should be done on all neonates with this phenotype to exclude Trisomy 18 as the two conditions share many common phenotypic features. 73,76,78 For those undergoing continued care, prolonged mechanical ventilation can be expected and a tracheostomy may have to be considered if extubation is not possible. 74 In addition, pulmonary hypertension may be present and may require treatment with sildenafil or iloprost to decrease the pulmonary pressures. 74 Echocardiography should be performed to exclude congenital cardiac abnormalities. 79,80

As PSS may be associated with central nervous system abnormalities,72,77 it is recommended to perform an MRI of the brain and to screen for endocrine abnormalities such as central hypothyroidism. 54 The presence of cerebral malformations may also increase the risk of seizures, which require anticonvulsant therapy.69,73,75 These patients may also sustain fractures postnatally as the bones are hypoplastic with decreased calcification. 78

Enteral feeding is often delayed due to short-gut syndrome 67,78 and intestinal malrotation, 79 necessitating prolonged parenteral nutrition. In addition, oral feeding may be impossible due to impaired swallowing, 80 and patients may require the surgical placement of a feeding gastrostomy tube.

Because of the wide array of physical abnormalities, a multidisciplinary approach is appropriate for those patients surviving the neonatal period who may require repeated surgical procedures for various craniofacial and skeletal deformities. Members of the team should include a pediatrician/neonatologist, occupational therapist, physiotherapist, speech therapist, and surgeons from various disciplines, including pediatric surgery, orthopedic surgery, maxillofacial surgery, and ENT surgery.

Patients with PSS are at an increased risk of malignant hyperthermia and bronchospasm during anesthesia. However, the use of sevoflurane for induction and maintenance, and rocuronium or vecuronium for muscle relaxation has been successful without adverse events reported in many patients. 74,75

**Prognosis**

Although the ultimate prognosis of PSS is dependent on the underlying cause, this condition has been described as almost uniformly lethal, with 30% of fetuses being stillborn and live-born infants usually dying within the first month of life. 68,72 However, survival beyond 12 months of age has been described, indicating that early mortality is not always inevitable. Of interest is a 9-year-old girl who underwent repeated surgical procedures for skeletal deformities 77 and a 21-year-old pregnant female who underwent cesarean section at 38 weeks of gestation with a normal fetus. 81 Early death is usually a result of primary cerebral malformations 68 or acute respiratory failure secondary to pulmonary hypoplasia.68,72 The degree of lung hypoplasia and the ability of the lungs to sustain life are dependent on the timing of onset, with early-onset akinesia associated with severe hypoplasia and demise. 78 After death, it is essential to request a postmortem as this will help describe the features of this rare condition even further. 69

**Subsequent pregnancies**

Patients who have delivered a fetus with PSS should have close fetal surveillance in subsequent pregnancies. This will allow the early recognition of anomalies. However, since the phenotypic condition is derived from heterogeneous causes, the counseling and recurrence risk calculation are imprecise. It has been estimated that the recurrence risk varies between 0% and 25%. 82

**Author contributions**

All authors contributed toward data analysis, drafting and critically revising the paper, gave final approval of the version.
Disclosure

The authors report no conflicts of interest in this work.

References


