Fetal Counseling for Congenital Malformations

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Kokila Lakhoo

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Abstract

Fetal counseling is best achieved by a multidisciplinary team that can favorably influence the perinatal management of prenatally diagnosed anomalies and provide this information to prospective parents. Prenatal diagnosis has remarkably improved our understanding of surgically correctable congenital malformations. It has allowed us to influence the delivery of the baby, offer prenatal surgical management, and discuss the options of termination of pregnancy for seriously handicapping or lethal conditions. Antenatal diagnosis has also defined an in utero mortality for some

K. Lakhoo (✉)
Paediatric Surgery, Children's Hospital Oxford, Oxford University Hospitals, University of Oxford, Oxford, UK
e-mail: kokila.lakhoo@paediatrics.ox.ac.uk

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lesions such as diaphragmatic hernia and sacrococcygeal teratoma so that true outcomes can be measured. The limitation of in utero diagnosis cannot be ignored. The aim of prenatal counseling is to provide information to prospective parents on fetal outcomes, possible interventions, appropriate setting, time and route of delivery, and expected postnatal outcomes, immediate and long term.

Keywords
Fetal counseling · Congenital surgical malformations

Introduction

Congenital malformations affect 3% of babies born in the United States and account for 20% of all infant death (Matthews et al. 2015; Sharma et al. 2017). The evolution of high-resolution imaging studies and perinatal testing techniques have revolutionized the prenatal diagnosis of structural abnormalities (Moaddab et al. 2017). As a consequence, congenital malformations are now diagnosed earlier and in a greater number of patients than even before. Prenatal diagnosis of a congenital anomaly may result in significant psychological distress for parents of affected babies. Counseling may assist parents to cope during this difficult time. The primary aim of prenatal counseling is to educate parents about their child's anomaly. Marokakis et al. (2016) performed a systematic review of prenatal counseling for congenital malformation and recommended that (1) prenatal counseling should be offered as soon as possible after parents receive their baby's diagnosis; (2) the health professionals involved in counseling should be knowledgeable, emphatic, and ideally those who will be involved in the future care of the baby; and (3) counseling should comprehensively cover all aspects of the condition diagnosed such as natural history of the anomaly, treatment options, prognosis, etc.

Advances in prenatal diagnosis and management often demand the need for pediatric surgeons to be involved in the prenatal care of the fetus. Pediatric surgeons are often called to counsel parents once a surgical abnormality is suspected on a prenatal scan. The referral base for a pediatric surgeon now includes the perinatal period. Expertise in surgical correction of congenital malformations may favorably influence the perinatal management of prenatally diagnosed anomalies, by changing the site of delivery for immediate postnatal treatment or altering the mode of delivery to prevent obstructed labor or hemorrhage: early delivery to prevent ongoing fetal organ damage or treatment in utero to prevent, minimize, or reverse fetal organ injury as a result of a structural defect. Recent literature has confirmed the favorable impact of prenatal surgical consultation in influencing the site of delivery in approximately 45%, changing the mode of delivery by 10%, reversing the decision to terminate a pregnancy by 4.6%, and changing the diagnosis in 7% of pregnancies (Patel et al. 2008).

Counseling parents about prenatally suspected surgically correctable anomalies should not be solely performed by obstetricians or pediatricians. Similarly, the pediatric surgeon performing these prenatal consultations must be aware of differences between the prenatal and postnatal natural history of the anomaly. There is often a lack of understanding of the natural history and prognosis of a condition presenting in the newborn and the same condition diagnosed prenatally.

The diagnosis and management of complex fetal anomalies require a multidisciplinary team encompassing obstetricians, neonatologists, geneticists, pediatricians, pediatric surgeons, and occasionally other specialists with expertise to deal with all the maternal and fetal complexities of a diagnosis of a structural defect. This team should be able to provide information to prospective parents on fetal outcomes, possible interventions, appropriate setting, time and route of delivery, and expected postnatal outcomes. The role of the surgical consultant, in this team, is to present information regarding the prenatal and postnatal natural history of an anomaly, its surgical management, and the long-term outcome (Lakhoo et al. 2012).

Congenital Malformation

Congenital malformations account for one of the major causes of perinatal mortality and morbidity. Single major birth defects affect 3% of newborns, and 0.7% of babies have multiple defects. The prenatal hidden mortality is higher since many will miscarry spontaneously. Despite improvements in perinatal care, serious birth defects still account for 20% of all deaths in the newborn period and an even greater percentage of serious morbidity later in infancy and childhood (CEMACH 2005). The major causes of congenital malformation are chromosomal abnormalities, mutant genes, multifactorial disorders, and teratogenic agents.

Prenatal Diagnosis

Prenatal diagnosis has remarkably improved our understanding of surgically correctable congenital malformations. It has allowed the fetal medicine professionals to influence the delivery of the baby, offer prenatal surgical management, and discuss the options of termination of pregnancy for seriously handicapping or lethal conditions. Antenatal diagnosis has also defined an in utero mortality for some lesions such as diaphragmatic hernia, omphalocele, and sacrococcygeal teratomas so that true outcomes can be measured. Prenatal ultrasound scanning has improved since its first use 30 years ago, thus providing better screening programs and more accurate assessment of fetal anomalies. Screening for Down's syndrome may now be offered in the first trimester (e.g., nuchal scan combined test) (Fig. 1) or second trimester (e.g., quadruple blood test) (Malone et al. 2005). Better resolution and increased experience with ultrasound scans have led to the recognition of ultrasound soft markers which have increased the detection rate of fetal anomalies but at the expense of higher false-positive rates.

Routine ultrasound screening can identify structural anomalies at the time of the routine anomaly scan (at around 20 weeks) or increasingly commonly at the time of the dating or nuchal translucency scan (at around 11–13 weeks' gestation). Pregnancies identified as being high risk maybe offered further invasive diagnostic investigations such as amniocentesis or chorionic villus sampling. Structural abnormalities difficult to define on ultrasound such as hindbrain lesions or in the presence of oligohydramnios or raised maternal BMI (body mass index) may be better imaged on ultrafast magnetic resonance imaging. With the increasing range of options and sophistication of diagnostic methods, parents today are faced with more information, choice, and decisions than ever before, which can create as well as help to solve dilemmas. The different tests and screening procedures commonly in use are outlined below.

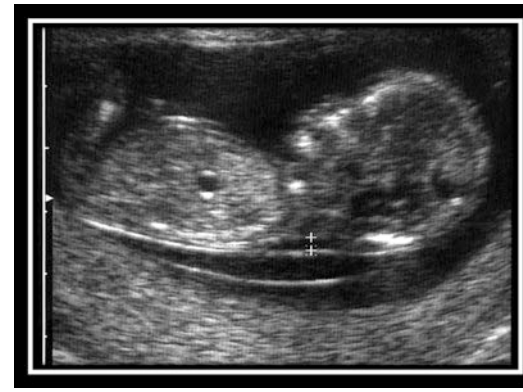

Fig. 1 Nuchal thickening

Fetal Imaging

Ultrasound Examination

Gray-scale ultrasound remains the main method of prenatal screening for fetal structural anomalies.

Most women are offered a first-trimester scan. The most accurate time to date a pregnancy is between 11 and 13 weeks. At this time, measurement of the nuchal translucency can also be performed. This involves measuring an area at the back of the baby's neck (Fig. 1). All fetuses have this, but there is an association between an increased nuchal thickness and the risk of a chromosomal abnormality. When combined with biochemical markers, this can give an estimation of

the risk of chromosomal disorders, the most common of which is T21, which is significantly more accurate than that based on maternal age alone. The combined test of nuchal translucency (NT), pregnancy-associated plasma protein-A (PAPP-A), and free β-human chorionic gonadotropin (free β-hCG) gives a detection rate of 85% for trisomy 21 with a false-positive rate of 3% (Engels et al. 2013).

An increased nuchal translucency with a normal karyotype can be associated with an increased risk of a range of structural anomalies and syndromes (Fig. 1).

The mechanisms by which some abnormalities give rise to this transient anatomical change of nuchal translucency are poorly understood (Collins and Impey 2012). Although some abnormalities can be seen at the time of the nuchal scan (11–14 weeks), most are detected at the 20-week anomaly scan. Some abnormalities such as gastroschisis have a higher detection rate on a scan than others, e.g., cardiac abnormalities.

If the nuchal translucency measurement is increased and the karyotype is normal, there is a higher risk for a cardiac anomaly, and these high-risk fetuses may be referred for fetal echocardiography, which provides better prenatal cardiac assessment than the routine screening scan (Pajkrt et al. 2004). Ultrasound surveillance is essential during the performance of invasive techniques such as amniocentesis, chorionic villus sampling (CVS), and shunting procedures. It is also useful for assessing fetal viability before and after such procedures. Some abnormalities such as tracheoesophageal fistula, bowel atresia, diaphragmatic hernia, and hydrocephaly may present later in pregnancy and thereby not detected on the routine 18-week scan.

Overall, around 60% of structural birth defects are detected prenatally, but the detection rate varies from 0% (isolated cleft palate) to close to 100% (gastroschisis) depending on the defect. True wrong diagnoses are rare, but false-positive diagnoses do occur; some are due to natural prenatal regression, but most are due to ultrasound "soft markers."

Ultrasound "soft markers" are changes noted on prenatal scan that are difficult to define. Examples are echogenic bowel (Patel et al. 2004), hydronephrosis, and nuchal thickening. Their presence creates anxiety among sonographers since the finding may be transient with no pathological relevance or may be an indicator of significant anomalies such as chromosomal abnormalities (Bricker et al. 2000), cystic fibrosis (echogenic bowel), Down's syndrome (nuchal thickening), or renal abnormalities (hydronephrosis). Once soft markers are detected should they be reported or further invasive tests offered is a dilemma faced by obstetricians. Reporting these markers has increased detection rates at the expense of high false-positive rates. The UK National Screening Committee now has a policy of which markers should and should not be reported (http://fetalanomaly.screening.nhs.uk/standardsandpolicies).

Three-dimensional images from new ultrasound machines are becoming increasingly commonplace. As well as delighting parents, these images can be useful for diagnosis and planning postnatal care, for example, with facial deformities. They are also leading to improved imaging and better diagnostic accuracy.

Fetal Echocardiography

The field of fetal echocardiography has seen a rapid expansion in the last decade to the extent that most structural cardiac anomalies can now be detected prenatally (Taketazu et al. 2006). Conditions such as diaphragmatic hernia, omphalocele, and duodenal atresia have a high association with cardiac anomalies. Identifying these cardiac anomalies prenatally has assisted in prenatal counseling and planning for postnatal management. Other conditions such as twin-to-twin transfusion, large cystic lung lesions, and sacrococcygeal teratomas may cause cardiac dysfunction which can be easily diagnosed or confirmed on echocardiography and help with predicting outcomes (Rogers et al. 2013).

Magnetic Resonance Imaging

The advantage of magnetic resonance imaging (MRI) over ultrasound for imaging intracranial abnormalities is well recognized especially for brainstem, posterior fossa, and neural tube anomalies (Pugash et al. 2008). Magnetic resonance imaging may assist in better defining some lesions

difficult to view on conventional prenatal scanning such as the presacral teratomas, posterior urethral valves in the presence of oligohydramnios, chest lesions, etc. MRI is also useful in the obese patient. Other advantages of MRI include the fact that the images can be examined offline by several readers, whereas 2D ultrasound images usually require real-time interpretation by the operator. At present MRI is complementary to ultrasound and is unlikely to replace conventional ultrasound scans (Garcia-Flores et al. 2013).

Minimally Invasive Diagnostic Tests

Prenatal Maternal Serum Screening

Interest in detecting circulating fetal cells (cffDNA = cell-free fetal DNA) in maternal blood for diagnostic purposes has grown since the advent of fluorescence-activated cell sorting (FACS) (Herzenberg et al. 1979) and is now becoming available commercially for the diagnosis of chromosomal anomalies. Fetal Rh-D typing for fetal blood group determination and fetal sex determination using cffDNA are now used routinely in the management of hemolytic diseases. Using cffDNA to diagnose single gene disorders is problematic, and further research is in need.

Genetic Diagnoses

Antenatal detection of genetic abnormalities is increasing especially in high-risk pregnancies with the discovery of less invasive testing. Preimplantation genetic diagnosis (PGD) has replaced invasive testing for many genetic conditions by process of sampling in vitro fertilized embryos and obtaining genetic analysis the same day so that unaffected embryos may be used for implantation. The most common indications are chromosomal abnormalities, X-linked diseases, and single gene disorders (Basille et al. 2009).

PGD has been successfully used for autosomal recessive disorders such as cystic fibrosis, autosomal dominant diseases including Huntington's disease, and X-linked disorders including fragile X syndrome and Duchenne muscular dystrophy. PGD is extremely promising for families affected by genetic disorders but has also given rise to many legal and ethical challenges such as its use to produce an unaffected, human leucocyte antigen (HLA) compatible "savior sibling."

Invasive Diagnostic Tests

Amniocentesis and chorionic villus sampling (CVS) are the two most commonly performed invasive diagnostic tests.

Amniocentesis

Amniocentesis is commonly used for detecting chromosomal abnormalities and less often for molecular studies, metabolic studies, and fetal infection. It is performed after 15-week gestation and carries a low risk of fetal injury or loss (0.5–1%). Full karyotype analysis takes approximately 2 weeks but newer.

RAPID techniques using FISH (fluorescent in situ hybridization) or PCR (polymerase chain reaction) can give limited (usually for trisomies 21, 18, and 13) results within 2–3 days.

Chorionic Villus Sampling (CVS)

CVS is the most reliable method for first-trimester diagnosis and can be performed after 10-week gestation. The test involves ultrasound-guided biopsy of the chorionic villi. The added risk for fetal loss is approximately 1–2%. The samples obtained may be subjected to a variety of tests including full karyotype, rapid karyotyping (FISH–PCR), enzyme analysis, or molecular studies. Approximate timing of chromosomal results is 1–2 weeks for karyotyping and 2–3 days for FISH and PCR.

Fetal Blood Sampling (FBS)

Rapid karyotyping of CVS and amniotic fluid samples FISH and PCR has replaced fetal blood sampling for many conditions. However, FBS is still required for the diagnosis and treatment of hematological conditions and some viral infections. When required it is usually performed by ultrasound-guided needle sampling after 18-week gestation rather than the more invasive fetoscopic technique. Mortality from this procedure is reported to be 1–2%.

Future Developments

The aim of prenatal diagnosis and testing is to have 100% accuracy without fetal loss or injury and no maternal risk. A national plan to improve Down's screening using ultrasound and biochemical combination tests is now in place in the United Kingdom. Research into new markers for chromosomal abnormalities is ongoing. The fetal nasal bone is one such example, which may assist in detecting babies with chromosomal abnormalities.

The search for fetal components in maternal blood is now available as the Harmony test.

Success in the genome projects for prenatal diagnosis of some genetic conditions has encouraged and excited scientist to continue research in this field.

Rapid detection techniques will soon replace traditional cultures for karyotyping. Microarray testing of fetal cells is rapidly being introduced; some advice microarray testing whenever a fetal structural anomaly is detected on scan. There are many ethical dilemmas involved with this, in particular because of the absence of any phenotype with fetal testing.

Fetal Surgery

There is a spectrum of interventions ranging from simple aspiration of cysts to open fetal surgery. Minimally invasive techniques, such as ablation of vessels in sacrococcygeal teratomas, fetoscopic ablation of posterior urethral valves, tracheal occlusion for congenital diaphragmatic hernia, etc., are either established or are currently under trial. However, laser ablation in twin-to-twin transfusion is now well established.

Specific Surgical Conditions

Congenital Diaphragmatic Hernia (CDH)

CDH accounts for 1 in 3000 live birth and challenges the neonatologist and pediatric surgeons in the management of this high-risk condition (Fig. 2). Mortality remains high (more than 60%) when the "hidden" mortality of in utero death and termination of pregnancy are taken into account. Lung hypoplasia and pulmonary hypertension account for most deaths in isolated CDH newborns. Associated anomalies (30–40%) signify a grave prognosis with a survival rate of less than 10%.

In the United Kingdom, most CDH are diagnosed at the 20-week anomaly scan with a detection rate approaching 60%, although as early as 11-week gestation has been reported. MRI has a useful role in accurately differentiating CDH from cystic lung lesions and may be useful in measuring fetal lung volumes as a predictor of outcome.

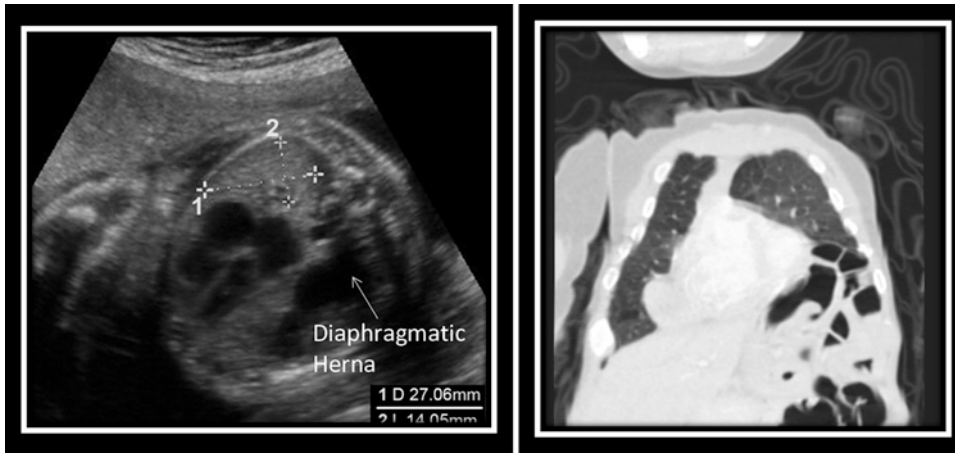

Fig. 2 Prenatal and postnatal images of left congenital diaphragmatic hernia

Cardiac anomalies (20%), chromosomal anomalies of trisomies 13 and 18 (20%), and urinary, gastrointestinal, and neurological (33%) can coexist with CDH and should be ruled out by offering the patient fetal echocardiogram, amniocentesis, and detailed anomaly scan. These associated anomalies and, in isolated lesions, early detection, liver in the chest, polyhydramnios, and fetal lung-head ratio (LHR) of less than 1 are implicated as poor predictors of outcome (Deprest and De Coppi 2012). In these patients with poor prognostic signs, fetal surgery for CDH over the last two decades has been disappointing; however, benefit from fetal intervention with temporary tracheal occlusion (FETO) has been reported in early European trials but awaits further randomized studies from Europe and United States (Dekoninck et al. 2011). Favorable outcomes in CDH with the use of antenatal steroids have not been resolved in the clinical settings. Elective delivery at a specialized center is recommended with no benefit from caesarean section.

Postnatal management (Haroon and Chamberlain 2013) is aimed at reducing barotrauma to the hypoplastic lung by introducing high-frequency oscillatory ventilation (HFOV) or permissive hypercapnia and treating the severe pulmonary hypertension with nitric oxide. No clear benefits for CDH with ECMO (extracorporeal membrane oxygenation) have been concluded in a 2002 Cochrane ECMO study (Elbourne et al. 2002).

Surgery for CDH is no longer an emergency procedure. Delayed repair following stabilization is employed in most pediatric surgical centers. Primary repair using the transabdominal route is achieved in 60–70% of patients with the rest requiring a prosthetic patch.

Cystic Lung Lesions

Congenital cystic adenomatoid malformations (CCAMs), bronchopulmonary sequestrations (BPS), or "hybrid" lesions containing features of both are common cystic lung lesions noted on prenatal scan. Less common lung anomalies include bronchogenic cysts, congenital lobar emphysema, and bronchial atresia. Congenital cystic lung lesions are rare anomalies with an incidence of 1 in 10,000 to 1 in 35,000.

Prenatal detection rate of lung cysts at the routine 18–20-week scan is almost 100% and may be the commonest mode of actual presentation (Fig. 3). Most of these lesions are easily distinguished from congenital diaphragmatic hernia; however, ultrasound features of CCAM or BPS are not sufficiently accurate and correlate poorly with histology. MRI though not routinely used may provide better definition for this condition.

Bilateral disease and hydrops fetalis are indicators of poor outcome, whereas mediastinal shift, polyhydramnios, and early detection are not poor

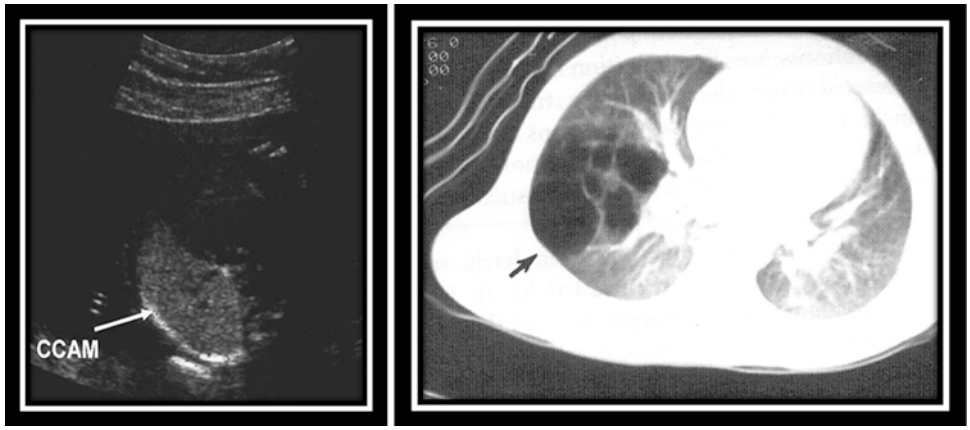

Fig. 3 Prenatal and postnatal images of CCAM

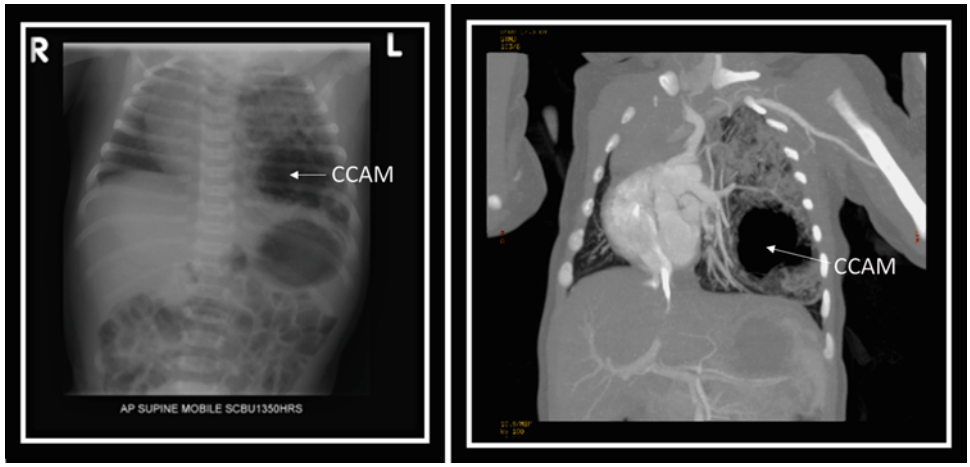

Fig. 4 Chest radiograph and CT scan showing left lower lobe CCAM

prognostic signs. Recently, CCAM volume ratio (CVR), ratio of the volume of CCAM/fetal head circumference, is shown to be an important determinant of outcome with a high CVR ratio indicative of poor outcome (Cass et al. 2013). In the absence of termination, the natural fetal demise of antenatally diagnosed cystic lung disease is 28%. Spontaneous involution of cystic lung lesions can occur, but complete postnatal resolution is rare, and apparent spontaneous "disappearance" of antenatally diagnosed lesions should be interpreted with care, as nearly half of these cases subsequently require surgery.

In only 10% of cases, the need for fetal intervention arises. The spectrum of intervention includes simple centesis of amniotic fluid, thoracoamniotic shunt placement, percutaneous laser ablation, and open fetal surgical resection (Adzick 2009). Use of maternal steroids has been reported to reverse hydrops in microscopic CCAM but not in macroscopic CCAM, and the mechanism of this response to maternal steroids is unclear (Curran et al. 2010). A large cystic mass (macroscopic CCAM) and hydrops in isolated cystic lung lesions are the only real indication for fetal intervention.

Normal vaginal delivery is recommended unless maternal conditions indicate otherwise. Large lesion is predicted to become symptomatic shortly after birth (as high as 45% in some series); thus delivery at a specialized center would be appropriate; however, smaller lesions are less likely to be symptomatic at birth and could be delivered at the referring institution with follow-up in a pediatric surgery clinic.

Postnatal management (Lakhoo 2010) is dictated by clinical status at birth. Symptomatic lesions require urgent radiological evaluation with chest radiograph and ideally CT scan (Figs. 3 and 4) followed by surgical excision. In asymptomatic cases, postnatal investigation consists of chest CT scan within 1 month of birth, even if regression or resolution is noted on prenatal scanning. Plain radiography should not be relied upon since it will miss and underestimate many lesions.

Surgical excision of postnatal asymptomatic lesions remains controversial, with some centers opting for conservative management. The approach to treating this asymptomatic group has evolved in some centers, whereby a CT scan is performed within 1 month post birth, followed by surgery before 6 months of age due to the inherent risk of infection and malignant transformation.

Abdominal Wall Defects

Omphalocele (exomphalos) and gastroschisis are both common but distinct abdominal wall defects with an unclear etiology and a controversial

prognosis. Attention may be drawn to their presence during the second trimester because of raised maternal serum alpha-fetoprotein level or abnormal ultrasounds scan.

Exomphalos

Exomphalos is characteristically a midline defect, at the insertion point of the umbilical cord, with a viable sac composed of amnion and peritoneum containing herniated abdominal contents (Fig. 5). Incidence is known to be 1 in 4000 live births. Associated major abnormalities which include trisomies 13, 18, and 21, Beckwith-Wiedemann syndrome (macroglossia, gigantism, exomphalos), Pentalogy of Cantrell (sternal, pericardial, cardiac, abdominal wall, and diaphragmatic defect), and cardiac, gastrointestinal, and renal abnormalities are noted in 60–70% of cases; thus karyotyping in addition to detailed sonographic review and fetal echocardiogram is essential for complete prenatal screening (Patel et al. 2009).

Fetal intervention is unlikely in this condition. If termination is not considered, normal vaginal delivery at a center with neonatal surgical expertise is recommended and delivery by caesarean section only reserved for large exomphalos with exteriorized liver to prevent damage. Surgical repair includes primary closure or a staged repair with a silo for giant defects (Islam 2012). Occasionally in vulnerable infants with severe pulmonary hypoplasia or complex cardiac abnormalities, the exomphalos may be left intact and allowed to slowly granulate and epithelialize by application of antiseptic solution (Morgan et al. 2012).

Gastroschisis

Gastroschisis is an isolated lesion that usually occurs on the right side of the umbilical defect with evisceration of the abdominal contents directly into the amniotic cavity. The incidence is increasing from 1.66 per 10,000 births to 4.6 per 10,000 births affecting mainly young mothers typically less than 20 years old. Associated anomalies are noted in only 5–24% of cases with bowel atresia, the most common coexisting abnormality. On prenatal scan with a detection rate of 100%, the bowel appears to be free floating or the loops may appear to be thickened due to damage by amniotic fluid exposure causing an inflammatory response and a "peel" formation or damage due to constriction of the mesentery causing delay in venous and lymphatic drainage. Dilated loops of bowel (Fig. 6) may be seen from obstruction secondary to protrusion from a defect or atresia due to intestinal ischemia.

Predicting outcome in fetuses with gastroschisis based on prenatal ultrasound finding remains a challenge. There is no consensus on bowel dilatation as a predictor of outcome (Mears et al. 2010; Huh et al. 2010). Also thickened matted bowel and Doppler measurements of the superior mesenteric artery are not accurate predictors of outcome. To reduce the rate of

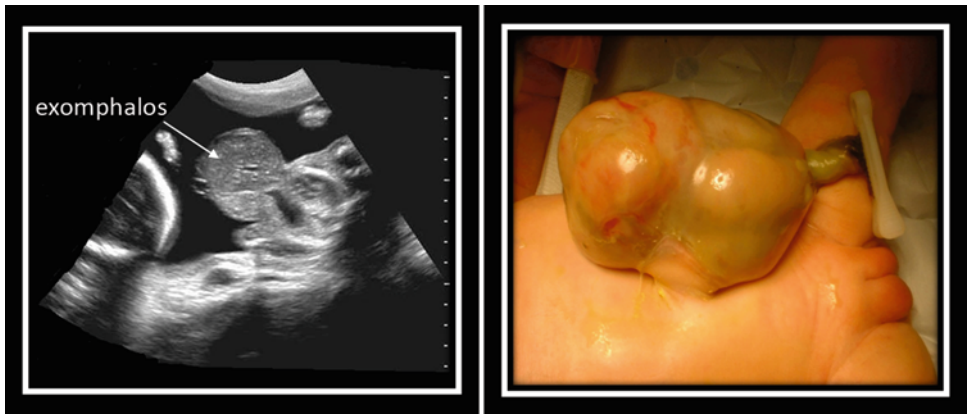

Fig. 5 Prenatal and postnatal images of exomphalos

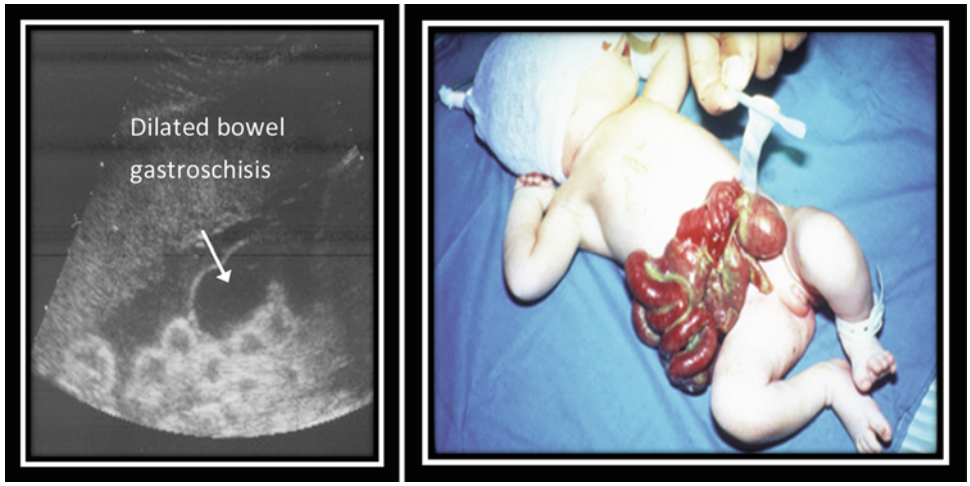

Fig. 6 Prenatal and postnatal images of gastroschisis

third-trimester fetal loss, serial ultrasounds are performed to monitor the development of bowel obstruction and delivery around 37 weeks recommended at a center with neonatal surgical expertise.

Delivery by caesarean section has no advantage to normal vaginal route. Despite efforts to plan elective delivery, 50% of cases will require emergency caesarean section due to development of fetal distress.

Various methods of postnatal surgical repair (Islam 2012) include the traditional primary closure, reduction of bowel without anesthesia, reduction by preformed silo, or by means of a traditional silo. Coexisting intestinal atresia could be repaired by primary anastomosis or staged with stoma formation. Variation in achieving full enteral feeding due to prolonged gut dysmotility is expected in all cases.

The long-term outcome in gastroschisis is dependent on the condition of the bowel. In uncomplicated cases, the outcome is excellent in more than 90% of cases.

Tracheoesophageal Fistula (TOF) and Esophageal Atresia (OA)

Repair of TOF/OA is a condition, which measures the skill of pediatric surgeons from trainee to independent surgeon (Fig. 7). The incidence is estimated at 1 in 3000 births. Prenatally, the condition may be suspected from maternal polyhydramnios and absence of a fetal stomach bubble at the 20-week anomaly scan. Prenatal scan diagnosis of TOF/OA is estimated to be less than 42% sensitive with a positive predicted value of 56% (Choudhry et al. 2007). Additional diagnostic clues are provided by associated anomalies such as trisomy (13, 18, 21), VACTERL sequence (vertebral, anorectal, cardiac, tracheoesophageal, renal, limbs), and CHARGE association (coloboma, heart defects, atresia choanae, retarded development, genital hypoplasia, ear abnormality). These associated anomalies are present in more than 50% of cases and worsen the prognosis; thus prenatal karyotyping is essential (Morgan et al. 2012). Duodenal atresia may coexist with TOF/OA. The risk of recurrence in subsequent pregnancies for isolated TOF/OA is less than 1%. Delivery is advised to be at specialized center with neonatal surgical input.

Postnatal surgical management is dependent on the size and condition of the baby, length of esophageal gap, and associated anomalies (Kunisaki and Foker 2012). Primary repair of the esophagus is the treatment of choice; however, if not achieved, staged repair with upper esophageal pouch care and gastrostomy or organ replacement with the stomach or large bowel are other options

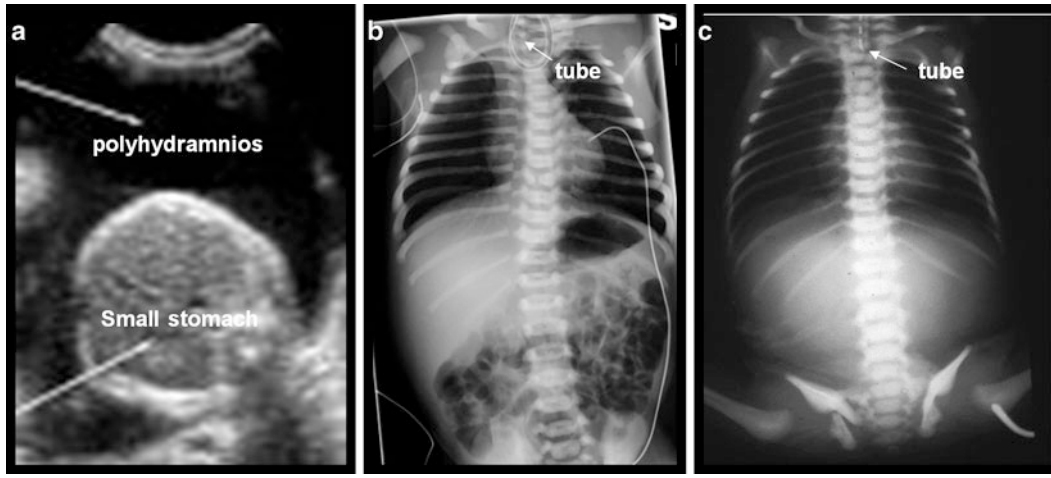

Fig. 7 (**a**) Prenatal imaging of suspected TOF with polyhydramnios and small stomach. (**b**) Plain radiograph showing esophageal pouch tube and distal gas confirming tracheoesophageal fistula with esophageal atresia. (**c**) Plain radiograph showing esophageal pouch tube and no abdominal gas confirming isolated esophageal atresia

(Friedmacher and Puri 2012). Associated anomalies require evaluation and treatment. Minimally invasive thoracoscopic approach to the repair of TOF may be offered by advanced pediatric endosurgical centers.

Early outcome of a high leak rate and esophageal stricture requiring dilatation in 50% of cases are expected where the anastomosis of the esophagus is created under tension (Burge et al. 2013).

Long-term outcomes are indicated by improved perinatal management and inherent structural and functional defects in the trachea and esophagus. In early life, growth of the child is reported to be below the 25 centile in 50% of cases, respiratory symptoms in two thirds of TOF/OA, and gastroesophageal reflux recorded in 50% of patients. Quality of life is better in the isolated group with successful primary repair as compared to those with associated anomalies and delayed repair (Koivusalo et al. 2005; Fallon et al. 2014).

Gastrointestinal Lesions

The presence of dilated loops of bowel (>15 mm in length and > 17 mm in diameter) on prenatal ultrasound scan is indicative of bowel obstruction.

Duodenal atresia has a characteristic "double bubble" appearance on prenatal scan, resulting from the simultaneous dilatation of the stomach and proximal duodenum. Detection rate on second-trimester anomaly scan is almost 100% in the presence of polyhydramnios and the "double bubble" sign. Associated anomalies are present in approximately 50% of cases with most notably trisomy 21 in 30% and cardiac anomalies in 20% and the presence of the VACTERL (17%) association (vertebral, anorectal, cardiac, tracheoesophageal, renal, and limbs) (Choudhry et al. 2009; Morgan et al. 2012, 2013).

The incidence of duodenal atresia is 1 in 5000 live birth. The postnatal survival rate is >95% with associated anomalies, low birth weight, and prematurity contributing to the <5% mortality. Temporary delay in enteral feeding occurs due to the dysmotility in the dilated stomach and duodenum.

There are many bowel abnormalities which may be noted on prenatal scanning such as dilated bowel, ascites, cystic masses, hyperperistalsis, polyhydramnios, and echogenic bowel (Ruiz et al. 2009); however, none is absolutely predictive of postnatal outcome. Patients with obstruction frequently have findings (especially in the third trimester) of bowel dilatation (Fig. 8), polyhydramnios, and hyperperistalsis. Ultrasound is

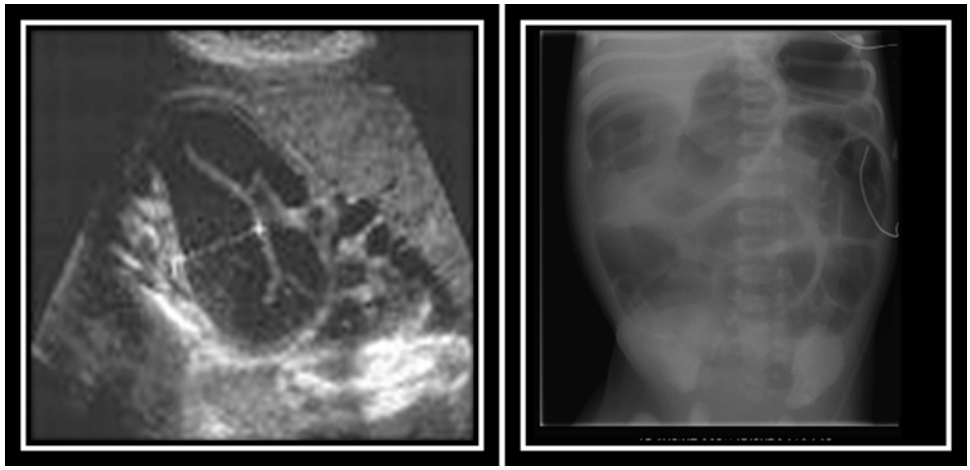

Fig. 8 Prenatal and postnatal imaging of intestinal atresia

much less sensitive in diagnosing large bowel anomalies than those with small bowel anomalies (Patel et al. 2004). Since the large bowel is mostly a reservoir, with no physiologic function in utero, defects in this region such as anorectal malformations or Hirschsprung's disease are very difficult to detect. Bowel dilatation and echogenic bowel may be associated cystic fibrosis; therefore, all such fetuses should undergo postnatal evaluation for this disease (Al-Kouatly et al. 2001). Prenatally diagnosed small bowel atresia does not select for a group with a worse prognosis, and survival rates are 95–100%.

Abdominal Cysts

Abdominal cystic lesions are not uncommonly diagnosed at antenatal ultrasound (US) examination (Fig. 9). A cystic mass identified in this way may represent a normal structural variant or a pathological entity requiring surgical intervention postnatally. Despite increasingly sophisticated equipment, some congenital anomalies have significant false-positive rates on US, and fetal cystic abdominal masses in particular can be difficult to diagnose accurately (Sherwood et al. 2008). Excluding cysts of renal origin, the differential diagnosis includes ovarian cysts, enteric duplication cysts, meconium pseudocyst, mesenteric cysts, and choledochal cysts. Less common diagnoses include extralobar pulmonary sequestration and pancreatic, splenic, urachal, and adrenal cysts. Almost all cysts are benign and many are self-limiting; however, these cysts create a high level of anxiety for the prospective parents, especially suspected adrenal cyst. Regular antenatal consultation and fetal counseling by the appropriate team may reduce parental anxiety levels. There is a very small role for fetal intervention. Resolution of these cysts was reported in 25% of cases, and 30% came to surgical intervention (Sherwood et al. 2008). Postnatal imaging is essential.

Sacrococcygeal Teratomas

Sacrococcygeal teratoma (SCT) is the commonest neonatal tumor accounting for 1 in 35,000 to 40,000 births (Fig. 10; Pauniaho et al. 2013). Four types have been defined, namely (Altman et al. 1974), type 1 external tumor with a small presacral component, type 2 external tumors with a large presacral component, type 3 predominantly presacral with a small external component, and type 4 entirely presacral. Type 4 carries the worst prognosis (Koivusalo et al. 2005) due to delay in diagnosis and malignant presentation. Doppler ultrasound is the diagnostic tool; however, fetal MRI provides better definition of the intrapelvic component. SCT is a highly vascular tumor, and

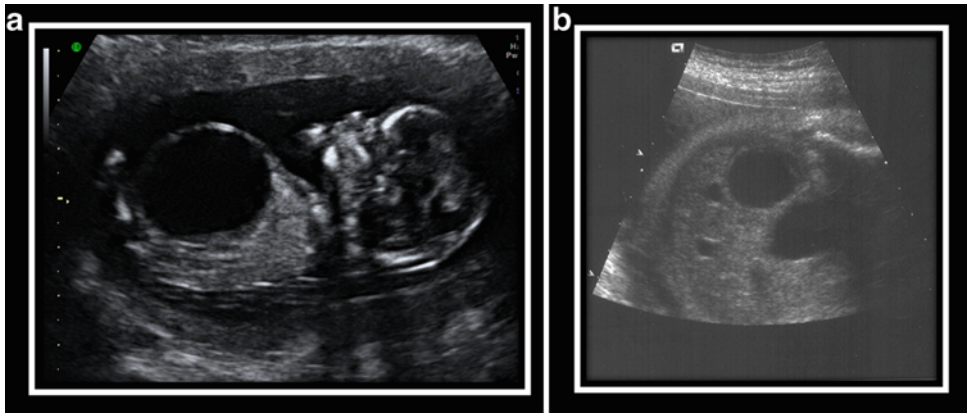

Fig. 9 (**a**) Prenatal abdominal cyst; (**b**) prenatal ovarian cyst

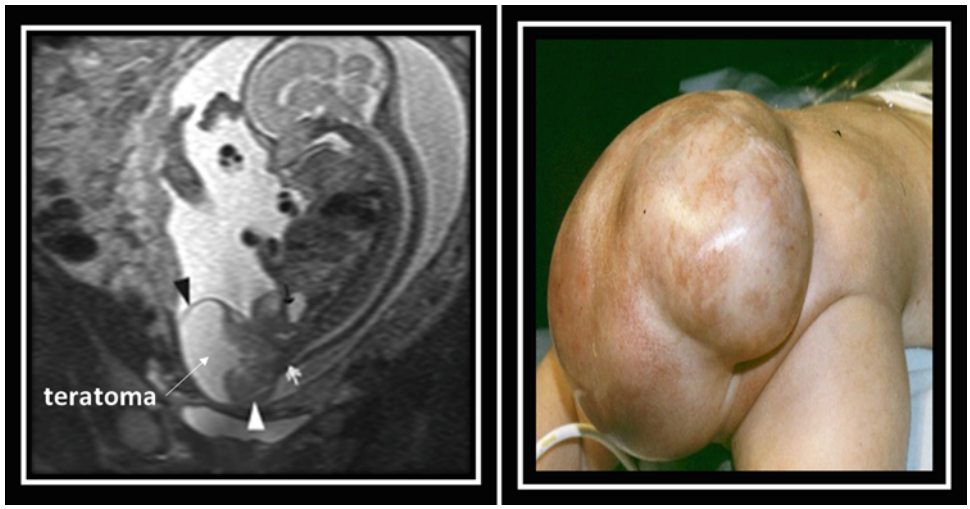

Fig. 10 Prenatal MRI and postnatal image of sacrococcygeal teratoma

the fetus may develop high cardiac output failure, anemia, and ultimately hydrops with a mortality of almost 100%. Fetal treatment of tumor resection or ablation of feeding vessel has been attempted in hydropic patients with minimal success. Caesarean section may be offered to patients with large tumors to avoid the risk of bleeding during delivery. Postnatal outcomes following surgery in type 1 and 2 lesions are favorable; however, type 3 and 4 tumors may present with urological and bowel problems with less favorable outcomes (Tailor et al. 2009). Long-term follow-up with alpha-fetoprotein and serial pelvic ultrasounds is mandatory to exclude recurrence of the disease (Usui et al. 2012).

Renal Anomalies

Urogenital abnormalities are among the commonest disorders seen in the perinatal period and account for almost 20% of all prenatally diagnosed anomalies (Brand et al. 1994). Many structural anomalies of the kidney and urinary tract can be detected by antenatal ultrasound, allowing early diagnosis and opportunity

to counsel parents and plan further investigations and management (Marokakis et al. 2016). The routine use of antenatal ultrasound scans has resulted not only in the early detection of these conditions but in selected cases has led to the development of management strategies, including fetal intervention aimed at preservation of renal function. Two major issues are the indications for intervention in bladder outlet obstruction and early pyeloplasty in infancy in cases with hydronephrosis (Chevalier 2004).

Prenatal evaluation of a dilated urinary tract is based on serial ultrasound scans as well as measurement of urinary electrolytes. Ultrasonography provides measurements of the renal pelvis, assessment of the renal parenchyma, as well as the detection of cysts in the cortex. In severe disease, lack of amniotic fluid may make ultrasound assessment of the renal tract difficult, and MRI may be helpful. Oligohydramnios is indicative of poor renal function and poor prognosis owing to the associated pulmonary hypoplasia. Urogenital anomalies coexist with many other congenital abnormalities, and amniocentesis should be offered in appropriate cases. It is estimated that 3% of infants will have an abnormality of the urogenital system, and half of these will require some form of surgical intervention (Steinhart et al. 1988).

Upper Urinary Tract Obstruction

Antenatal hydronephrosis accounts for 0.6–0.65% pregnancies (Davenport et al. 2013). The most common cause of prenatal hydronephrosis is pelvi-ureteric junction (PUJ) obstruction, others being transient hydronephrosis, physiological hydronephrosis, multicystic kidney, posterior urethral valves, ureterocele, ectopic ureter, etc. The prognosis is excellent in antenatally diagnosed unilateral hydronephrosis and in renal pelvic diameter of <10 mm. Spontaneous resolutions are noted in 20% of patients at birth and 80% at 3 years of age. Only 17% of prenatally diagnosed hydronephrosis need surgical intervention. Postnatal management of hydronephrosis requires ultrasound at birth and at 1 month of age and further evaluation with imaging and scintigraphy if an abnormality is suspected. The nonoperative treatment of antenatally detected hydronephrosis has been carefully monitored over a 17-year period, and from an analysis of six patient series, the conclusion is that this approach is safe (Joseph 2006).

Lower Urinary Tract Obstruction

Posterior urethral valves (PUV) are the most common cause for lower urinary tract obstruction in boys with an incidence of 1 in 2000–4000 live male births. The diagnosis of PUV is suspected on the prenatal ultrasound finding of bilateral hydronephrosis associated with a thickened bladder and decreased amniotic fluid volume (Fig. 11). Serial fetal urine analysis may provide prognostic information on renal function. Prenatal diagnosis for patients with PUV is a poor prognostic sign with 64% incidence of renal failure and transient pulmonary failure, compared to 33% in the postnatally diagnosed patients (Walsh and Johnson 1999). Pulmonary hypoplasia secondary to oligohydramnios largely contributes to the morbidity and mortality from fetal urethral obstruction (Ruano et al. 2016). Outcomes of fetal intervention with vesico-amniotic shunting or fetal cystoscopic ablation of urethral valve have not been very successful. Almost 90% of fetuses with urinary tract dilatation will not require fetal intervention. Fetal intervention may play a role in severe cases with progressive renal dilatation and development of oligohydramnios.

Postnatal management includes ultrasound confirmation of the diagnosis, bladder drainage via a suprapubic or urethral route, and contrast imaging of the urethra. Primary PUV ablation, vesicostomy, and ureterostomy are postnatal surgical options. The overall outcome from this disease is unfavorable (Joseph 2006; Matsell et al. 2016).

Conclusion and Future Directions

The boundaries of pediatric surgical practice have been extended by prenatal diagnosis. The care of patients with surgically correctable defects can now be planned prenatally with the collaborative effort of obstetricians, geneticists, neonatologists, and pediatric surgeons. Essential to prenatal counseling is the understanding of the specific

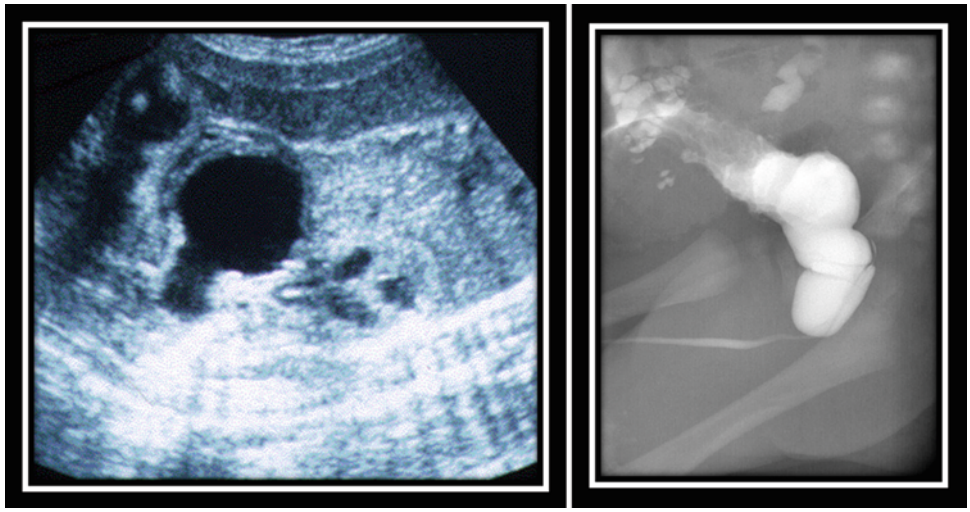

Fig. 11 Prenatal and postnatal imaging of posterior urethral valves

surgical condition's prenatal natural history, the limitations of prenatal diagnosis, the detection of associated anomalies, the risks and indications of fetal intervention programs, and the postnatal outcomes. Prenatal counseling is an essential component of pediatric surgical practice and should be ensured in the training programs for future pediatric surgeons.

Cross-References

- ▶ Congenital Diaphragmatic Hernia
- ▶ Congenital Esophageal Stenosis
- ▶ Duodenal Obstruction
- ▶ Fetal Surgery
- ▶ Jejunoileal Atresia and Stenosis

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