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PEDIATRIC ONCOLOGIC IMAGING

Ovarian neoplasms of childhood

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Abstract

Ovarian neoplasms are rare in children. Although usually asymptomatic, they sometimes present with abdominal pain, abdominal distension or palpable mass. The distribution of neoplasms in the pediatric population is different from in adults; benign mature cystic teratoma is the most common ovarian tumor in children. Radiologists should be familiar with the variable sonographic, CT and MRI findings of ovarian neoplasms. Although the less frequently encountered ovarian malignancies cannot be reliably distinguished by imaging alone, it does play an important role in workup. This review discusses the imaging and relevant clinical manifestations of the more commonly encountered pediatric ovarian neoplasms.

Keywords Children · Magnetic resonance imaging · Malignancy · Neoplasm · Ovary · Ultrasound

Introduction

Ovarian neoplasms in the pediatric population are rare, with a reported incidence of 2.6 per 100,000 girls per year [1]. Ovarian malignancies are even rarer. In a population-based study by Brookfield et al. [2], the age-adjusted incidence of ovarian malignancies was 0.102 per 100,000 girls per year in girls younger than 9 years and 1.072 per 100,000 girls per year in girls 10–19 years of age. Although older children and adolescents have a higher age-adjusted incidence of ovarian malignancy, it is worth noting that Oltmann et al. [3] found that in the setting of a known ovarian mass, there is a greater chance of malignancy in children 8 years and younger (22%) than in children older than 9 years (10%), further corroborated by a 3-fold greater odds ratio for malignancy. This is likely explained by the presence of benign ovarian cysts in peri- and postmenarchal females.

The 2014 World Health Organization (WHO) classification of tumors of the ovary includes germ cell tumors, surface epithelial tumors, and sex cord–stromal tumors (Table 1) [4]. Other less common but notable subtypes are germ cell–sex cord–stromal tumors (including gonadoblastoma) and miscellaneous tumors such as small cell carcinoma of the ovary [4]. Unlike the adult population, in which malignant surface epithelial neoplasms are most common, germ cell tumors are the most commonly encountered ovarian neoplasms in the pediatric population, followed by surface epithelial tumors and sex cord stromal tumors (Table 2) [5–7].

When an ovarian tumor is detected in children, consideration of a cancer predisposition syndrome is warranted (Table 3) [8]. For example, recent studies have confirmed that a high percentage of Sertoli-Leydig cell tumors arise in the setting of DICER1 syndrome. A review of 37 cases by Schultz et al. [9] found that 96% were associated with a *DICER1* mutation and 59% were specifically associated with a *DICER1* germline mutation. De Kock at al. [10] found that 100% of moderately and poorly differentiated Sertoli-Leydig cell tumors contained a *DICER1* mutation, and 70% contained a *DICER1* germline mutation. The manifestations of DICER1 syndrome are manifold and include pleuropulmonary blastoma, Wilms tumor, cystic nephroma, genitourinary embryonal rhabdomyosarcoma, multinodular goiter and thyroid carcinoma [11]. While the identification of a cancer predisposition syndrome does not influence treatment, it does impact future screening for additional tumors and surveillance of family members.

Presenting symptoms of ovarian neoplasms include abdominal pain, abdominal distension or palpable mass, and precocious puberty. Prior investigations have sought to distinguish benign from malignant ovarian lesions based on clinical presentation. Following a retrospective review of 424 children and adolescents whose ovarian findings were surgically managed, Oltmann et al. [3] found that 65% percent of the children

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Table 1 World Health Organization classification of tumors of the ovary

Germ cell tumors	Surface epithelial stromal tumors	Sex cord–stromal tumors
Mature cystic teratoma	Serous cystadenoma	Juvenile granulosa cell tumor
Immature teratoma	Mucinous cystadenoma	Sertoli-Leydig cell tumors
Dysgerminoma	Borderline tumors	Sclerosing stromal tumor
Mixed germ cell tumors	Cystadenocarcinoma	Sex cord tumor with tubular annules
Yolk sac tumor		Fibroma
Choriocarcinoma		Thecoma

with benign lesions and 42% of those with malignant lesions presented with abdominal pain. Similarly, Madenci et al. [12] found that 57% of people with both benign and malignant lesions presented with abdominal pain. Occasionally abdominal pain is secondary to ovarian torsion (Fig. 1). A recent 15½-year review of 114 girls with operatively confirmed ovarian torsion found that an ovarian neoplasm was present in 26% of cases; only 3.5% of these were malignant [13]. Several surgical series have found that abdominal distension and palpable mass on physical exam are more common in malignant ovarian lesions (28–46%) than in benign ovarian lesions (8–21%) [3, 12, 14]. Girls might also present with precocious puberty. This is most commonly associated with juvenile granulosa cell tumor but has also been reported in germ cell tumors and Sertoli-Leydig cell tumors [15–17].

Tumor markers can be useful in diagnosis as well as to monitor treatment and for post-treatment surveillance (Fig. 2). Tumor markers, including α-fetoprotein (AFP), β-human chorionic gonadotrophin (HCG), lactate dehydrogenase (LDH) and inhibin, are positive in up to 54–83% of malignant lesions (Table 4) [3, 14]. It is important to note that absence of elevated tumor markers does not exclude malignancy. Moreover, a 2012 literature review consisting of pooled data including 340 children with ovarian neoplasms and positive tumor markers found that 20% of benign germ cell tumors were associated with an elevated AFP, LDH or cancer antigen 125 (Ca-125) [18].

Ultrasound is the first-line imaging modality for assessing ovarian neoplasms. Sonographic findings that favor malignancy include large size (greater than 8–10 cm) and the presence of solid components [3, 14]. In an effort to avoid adnexectomy and preserve fertility, several scoring systems have been published and applied to the pediatric population. In females less than 19 years of age, a DePriest score <7 (based on lesion volume, cyst wall and septal structure) has a sensitivity of 88% and specificity of 95% for benignity; a Ueland index score <7 (based on lesion volume and tumor morphology) has a sensitivity of 90% and specificity of 92% for benignity [19].

Table 2 Frequency of ovarian tumors in the pediatric population [5–7]

World Health Organization classification	Frequency (%)
Germ cell tumor	58–70
Surface epithelial stromal tumors	15–19
Sex cord–stromal tumors	9–18
Miscellaneous	5–9

Germ cell tumors

Germ cell tumors, the most common pediatric ovarian neoplasms, originate from pluripotent germ cells. The majority are benign.

Mature cystic teratoma

Benign mature cystic teratoma is the most common ovarian neoplasm in children [5, 7]. These arise from at least two of the three germ cell layers (endoderm, mesoderm, ectoderm). Usually ectodermal predominant (containing hair, skin, fat and teeth), they are often referred to as dermoid cysts (Fig. 3). Most mature cystic teratomas are incidentally discovered, either on physical exam, imaging, or surgery for other indications. A review of 517 cases over a 14-year period found that 60% of patients are asymptomatic; those who are not might present with pain (23%) [20]. Mean tumor size is 6.5 cm, and 10% are bilateral [20].

Because of their variable content, mature cystic teratomas have a variable sonographic appearance. The most common appearance is that of cyst with echogenic nodule (Rokitansky

Table 3 Ovarian tumors associated with cancer predisposition syndromes [8]

Ovarian tumor	Cancer predisposition syndrome
Juvenile granulosa cell tumor	Ollier disease
	Maffucci syndrome
Sertoli-Leydig cell tumor	DICER1 syndrome
Gonadoblastoma	WT-1-related disorders
	Turner (45X0/46XY)
Sex cord tumor with annular tubules	Peutz-Jeghers syndrome
Small cell carcinoma	Rhabdoid tumor predisposition syndrome 2

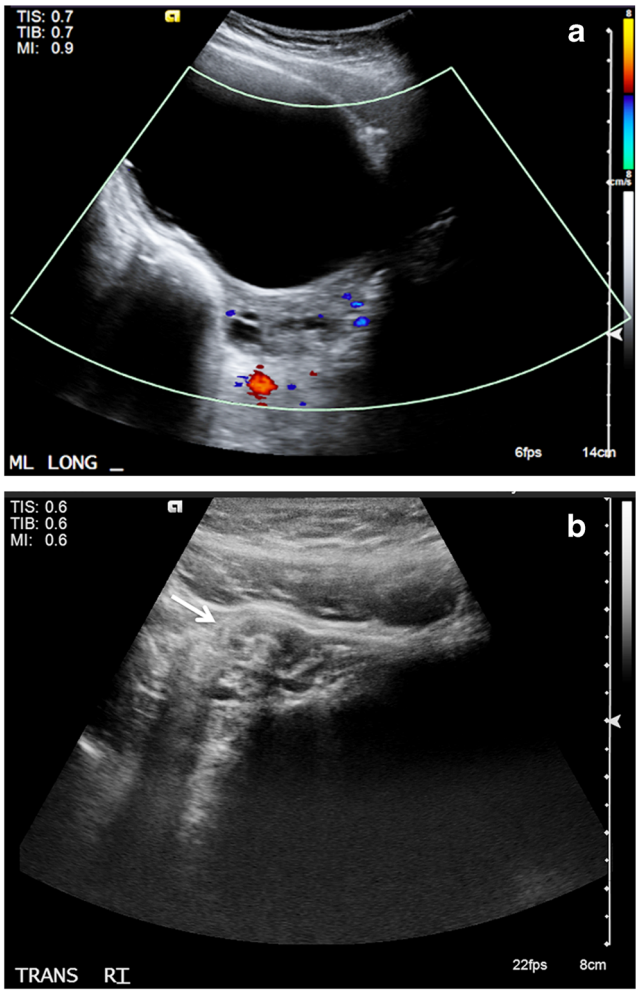

Fig. 1 Mucinous cystadenoma in a 15-year-old girl presenting with acute-onset right lower quadrant abdominal pain secondary to right ovarian torsion. **a** Longitudinal ultrasound image of the right ovary shows a large unilocular cystic mass arising from the right ovary. **b** Transverse ultrasound image through the right lower quadrant shows twisted gonadal vessels (*arrow*), consistent with ovarian torsion

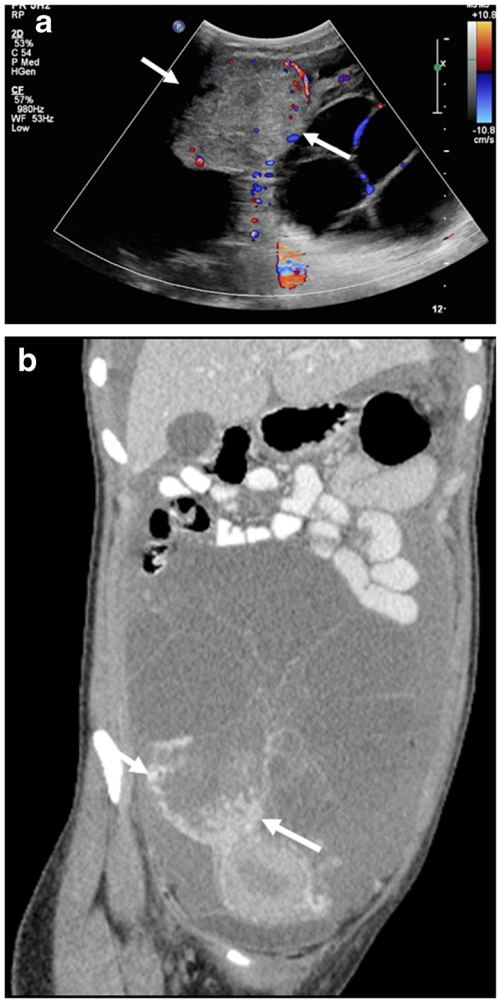

Fig. 2 Tumor markers in a 15-year-old girl with a 1-month history of abdominal pain and distension. **a** Transverse ultrasound image of the pelvis shows bilateral adnexal cysts with an intervening solid mass (*arrows*). **b** Coronal contrast-enhanced CT scan shows a heterogeneous solid vascular mass (*arrows*) that proved to be a gestational choriocarcinoma. The large adnexal cysts were secondary to ovarian hyperstimulation. Serum β-human chorionic gonadotrophin was markedly elevated

nodule — composed of hair, fat and bone) arising from the cyst wall, often with posterior acoustic shadowing (Fig. 4) [21, 22]. A Rokitansky nodule with posterior acoustic shadowing might extend to or arise from the superficial portion of the lesion such that the deep portion of the lesion is obscured (Fig. 5). This is referred to as to the "tip of the iceberg" sign. Other sonographic features include fat–fluid levels from layering echogenic fatty sebum (Fig. 6) and the "dermoid mesh" sign of hyperechoic dots and lines from hair (Fig. 7) [21–23]. Bowel gas, hemorrhagic ovarian cysts, endometriomas and perforated appendicitis have been misdiagnosed as mature cystic teratoma, and vice versa (Figs. 8 and 9) [24, 25]. Imaging with CT and MRI is straightforward. Fat and calcification seen on CT in 93% and 56% of cases, respectively, allow for a definitive diagnosis in 98% of cases (Fig. 10) [26]. Fat-suppression and chemical shift MR imaging techniques can distinguish fat and sebaceous fluid from other sources of T1 shortening (typically hemorrhage) and allow for detection of small foci of fat (Figs. 11 and 12).

Complications of ovarian mature cystic teratoma include ovarian torsion (3–16%), spontaneous rupture (1–3%) and infection [20, 27, 28]. As many as 36% of cases of anti-NMDA receptor encephalitis are associated with mature cystic teratoma [29].

Immature teratoma

Immature teratoma is a malignant germ cell tumor. Like the mature cystic teratoma, an immature teratoma arises from three germ cell layers but is distinguished by the presence of

Table 4 Tumor markers and associated ovarian neoplasms

α-fetoprotein[a]	Yolk sac tumor
	Immature teratoma
	Embryonal carcinoma
	Mixed germ cell tumor
	Sertoli-Leydig cell tumor
β-human chorionic gonadotrophin	Choriocarcinoma
	Embryonal carcinoma
	Dysgerminoma
Inhibin	Juvenile granulosa cell tumor
Lactate dehydrogenase[a]	Dysgerminoma

[a] Sometimes test positive in children with mature cystic teratoma

embryonic tissue, usually immature neural elements [30]. Up to 66% of cases have yolk sac elements, resulting in an elevated serum AFP [30, 31]. Within the pediatric population, the mean age at presentation is 10 years [32]. Because of their large size (5–42 cm), people most often present with palpable mass on physical exam [30, 33]. Most children and adolescents present with Stage I or II disease, which is treated with complete surgical resection [32, 33]. Prognosis for Stages I and II disease is favorable with a 4-year event-free survival of 98% [33]. Tumor grade and the presence of yolk sac elements are considered important risk factors for recurrent disease [33, 34].

Tumor size can help to differentiate the larger immature teratoma (mean tumor diameter of 16 cm) from mature cystic teratoma (mean tumor diameter of 6.5 cm). Although both may contain foci of fat and calcification, immature teratoma has solid components or is completely solid (Fig. 13) [35]. Careful attention to the contralateral ovary is warranted because 10% of immature teratomas are associated with mature cystic teratoma in the contralateral ovary [36].

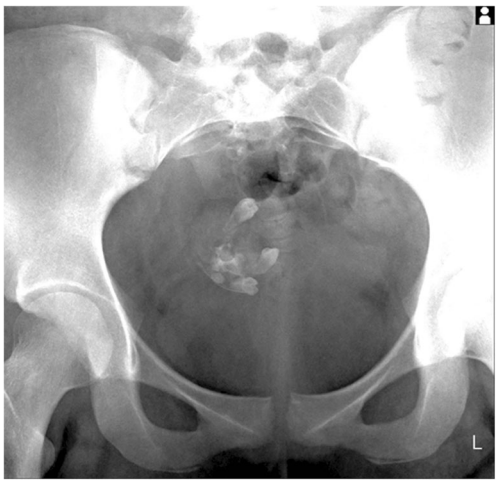

Fig. 3 Mature cystic teratoma in a 17-year-old girl with lower back pain for 1 year. Anteroposterior radiograph of the sacrum reveals several teeth in the pelvis, consistent with a mature cystic teratoma

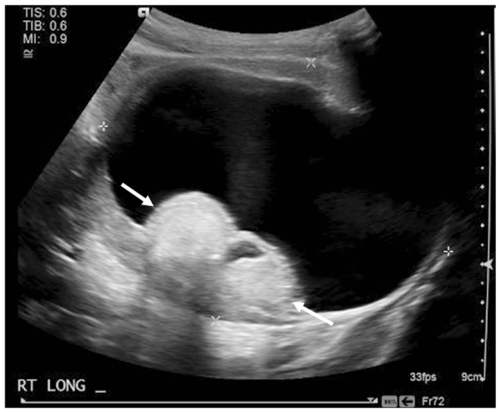

Fig. 4 Mature cystic teratoma in a 5-year-old girl presenting to the emergency room with right lower quadrant pain. Longitudinal ultrasound image shows a unilocular cystic mass with hyperechoic mural nodule (*arrows*) called a Rokitansky nodule, consistent with a mature cystic teratoma

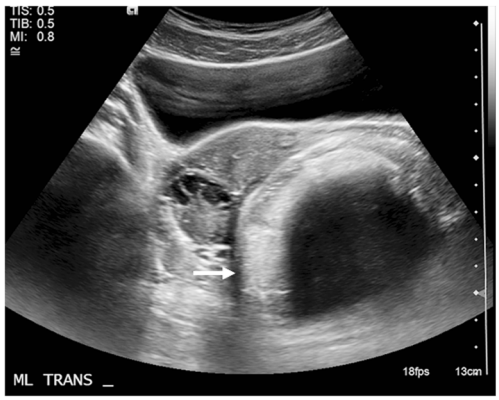

Fig. 5 Mature cystic teratoma in a 13-year-old girl with a 6-week history of abdominal pain. Transverse ultrasound imaging through the pelvis shows a left ovarian echogenic mass (*arrow*) with posterior acoustic shadowing obscuring the deep portions of the lesion. This is termed "tip of the iceberg"

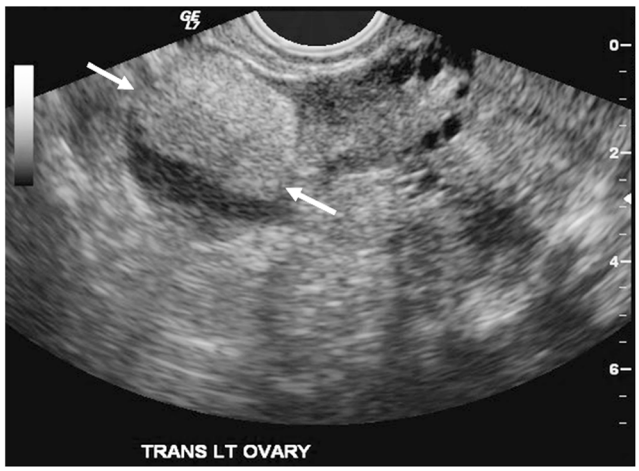

Fig. 6 Mature cystic teratoma in a 17-year-old girl with irregular menses. A transverse transvaginal ultrasound image shows a left ovarian mature cystic teratoma with a fluid–fluid level (*arrows*). The fatty echogenic sebum is rising to the anti-dependent aspect of the lesion

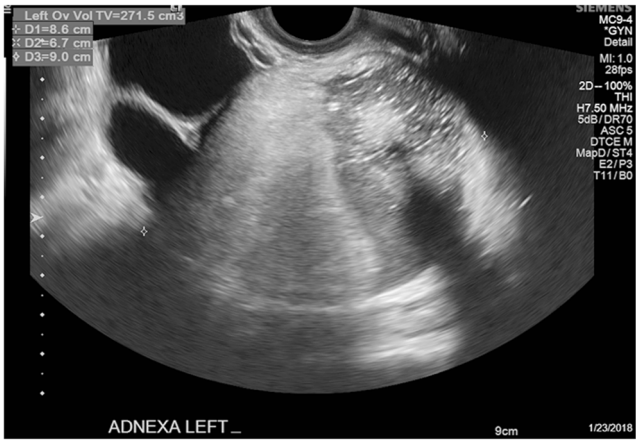

Fig. 7 Mature cystic teratoma in an 18-year-old woman presenting to the emergency room with a 3-day history of pain. A transverse transvaginal ultrasound image of the left ovary shows a mass with linear echogenic foci, consistent with hair within a mature cystic teratoma, or a "dermoid mesh"

Gliomatosis peritonei refers to the peritoneal deposition of mature glial cells, usually in children with immature teratoma but also reported in those with mixed germ cell tumor as well as mature cystic teratoma with malignant transformation [37]. The two major theories regarding the development of gliomatosis peritonei are (1) tumor rupture with spill of glial elements and (2) metaplasia of pluripotent stem cells secondary to factors produced by the tumor [38]. Gliomatosis peritonei does not affect tumor staging but its impact on tumor recurrence and survival remains unclear. In a review of 44 children and adolescents treated with surgical resection for Stages I and II immature teratoma, including 12 with associated gliomatosis peritonei, Cushing et al. [33] found that only 1 child who also had gliomatosis peritonei presented with recurrence. In contrast, Mann et al. [39] reported a statistically

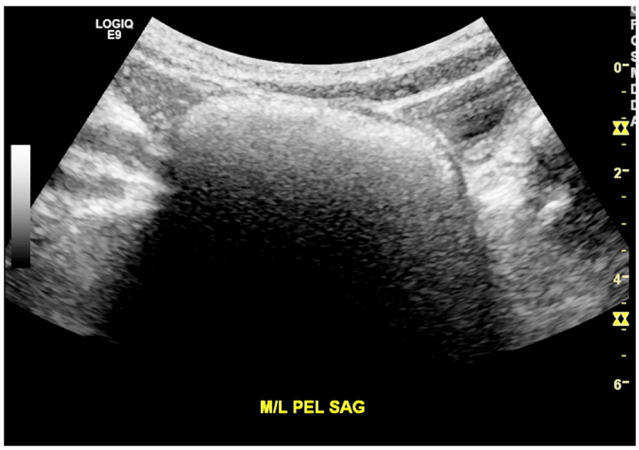

Fig. 8 Misinterpreted teratoma in a 5-year-old girl. The girl presented with a palpable mass on physical exam. Transverse ultrasound image of the pelvis shows an echogenic mass-like lesion with posterior acoustic shadowing, interpreted as a "tip of the iceberg" sign in a mature cystic teratoma. However, laparoscopy revealed normal ovaries bilaterally. Sonographic findings are most likely explained by bowel gas

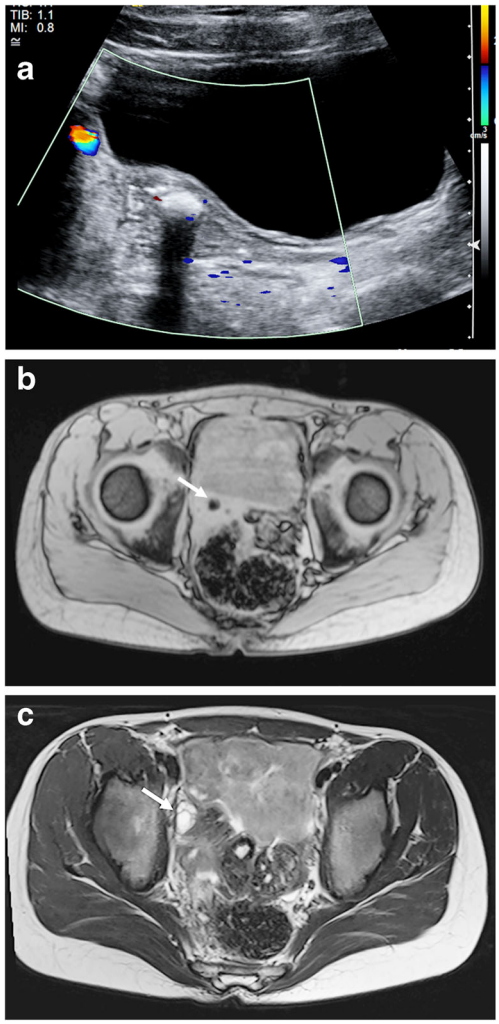

Fig. 9 Misinterpretation in a 7-year-old girl presenting with abdominal fullness. **a** Transverse ultrasound image through the bladder shows an echogenic focus with posterior acoustic shadowing. Normal right ovarian parenchyma was not identified. The diagnosis of a right ovarian mature cystic teratoma was suggested. **b** Axial out-of-phase MR image through the pelvis shows a focus of susceptibility artifact (*arrow*) corresponding to sonographic finding, consistent with calcification. **c** Axial T2-weighted MR image through the pelvis shows a normal right ovary (*arrow*) separate from the focus of calcification, which was ultimately attributed to a calcified Deflux implantation, supported by additional history that was subsequently obtained

significant higher relapse rate among people with immature teratoma with gliomatosis peritonei than without gliomatosis peritonei. MRI imaging demonstrates T2 hyperintense foci within the peritoneal cavity, ascites, and foci of nodular enhancement (Fig. 14); however, these findings can also be seen with malignant peritoneal implants [40].

Dysgerminoma

Dysgerminoma, the most common malignant germ cell tumor, is the most common ovarian malignancy in children overall

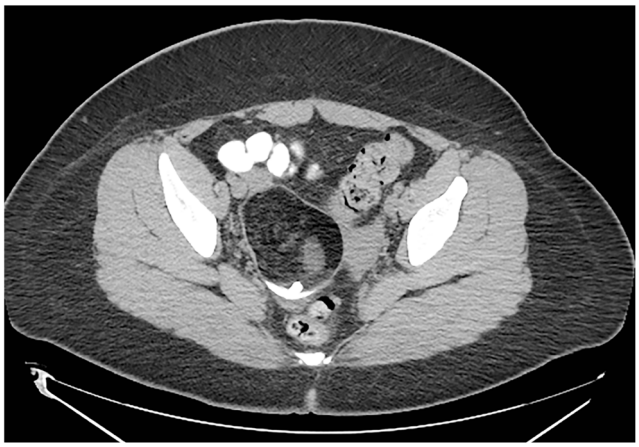

Fig. 10 CT of a mature cystic teratoma in a 17-year-old girl presenting with hematuria. Axial unenhanced CT scan through the pelvis shows an incidental mass with calcification and fat, consistent with a mature cystic teratoma

[41]. The majority (82%) occur in people between 10 years and 29 years of age, with a minority (6%) in children younger than 10 years [41]. LDH has been found to be positive in up to 95% of people with dysgerminomas [42]. Because of the presence of syncytiotrophoblastic cells, 5% of dysgerminomas produce HCG [43]. Approximately 70% of people present

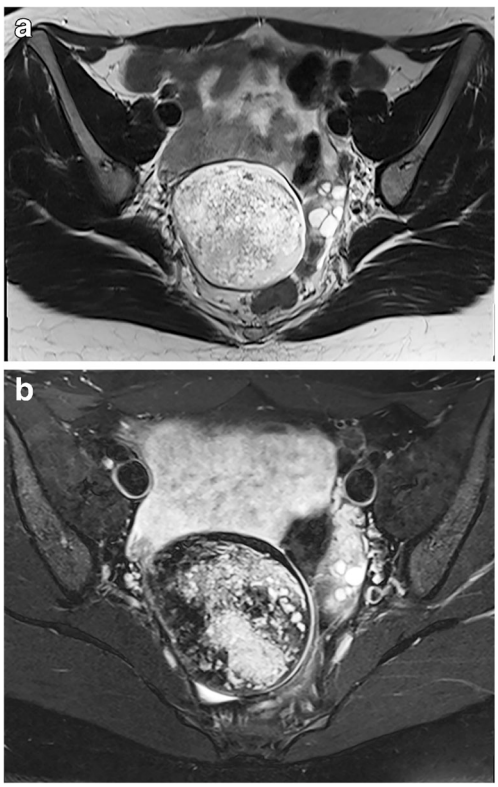

Fig. 11 MRI of mature cystic teratoma in a 16-year-old girl. **a** Coronal oblique T2-weighted image through the pelvis shows heterogeneous predominantly T2 hyperintense mass. **b** Axial fat-suppressed T2-weighted image shows loss of signal within the peripheral and central portions of lesion, consistent with fat

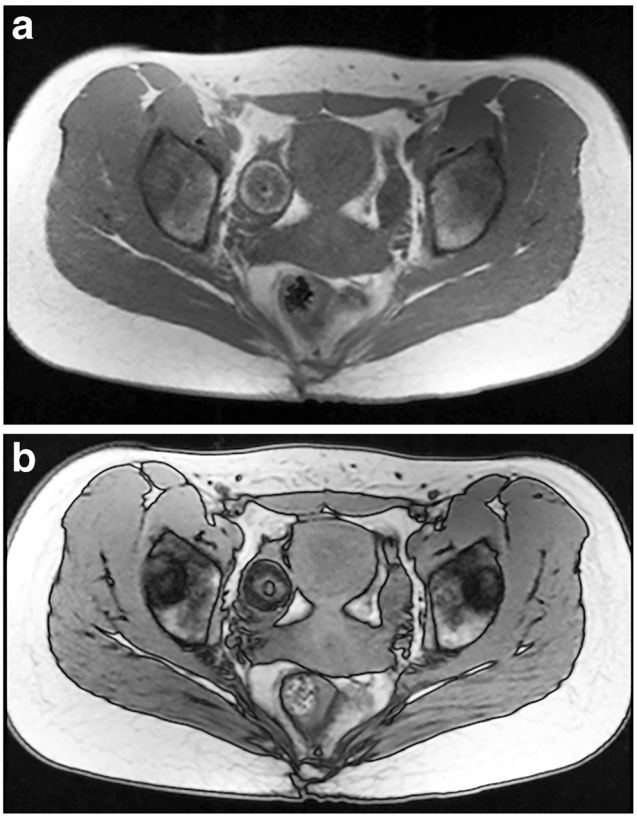

Fig. 12 MRI of mature cystic teratoma in a 15-year-old girl. **a** Axial in-phase image through the pelvis shows a right ovarian mass with a rim of T1 hyperintensity. **b** Axial opposed-phase image through the pelvis shows loss of signal in the corresponding region, confirming the presence of fat

with Stage IA disease and are treated with surgical resection [44, 45]. Relapse occurs in 13–20% of cases, usually within 19–24 months [44, 45].

Sonographic findings of dysgerminoma include a solid mass with regions of necrosis, hemorrhage and speckled calcifications; hypoechoic fibrovascular septa might also be present (Fig. 15) [46]. Necrotic foci and speckled calcifications might also visible on CT (Fig. 16). On MRI, fibrovascular septa appear as enhancing T2 hypointense bands (Fig. 17) [47]. It is bilateral in 10–15% of cases [41].

Dysgerminoma is the most common gonadal malignancy in people with gonadal dysgenesis, developing within a gonadoblastoma [8]. No definite cancer predisposition syndrome is associated with dysgerminoma.

Germ cell–sex cord tumors

Gonadoblastoma is a benign tumor originating from germ cells and Sertoli and granulosa cells. Forty percent of cases are bilateral [48]. Most cases arise in phenotypically female patients with disorders of sex development and Y-chromosome material, most commonly in Turner

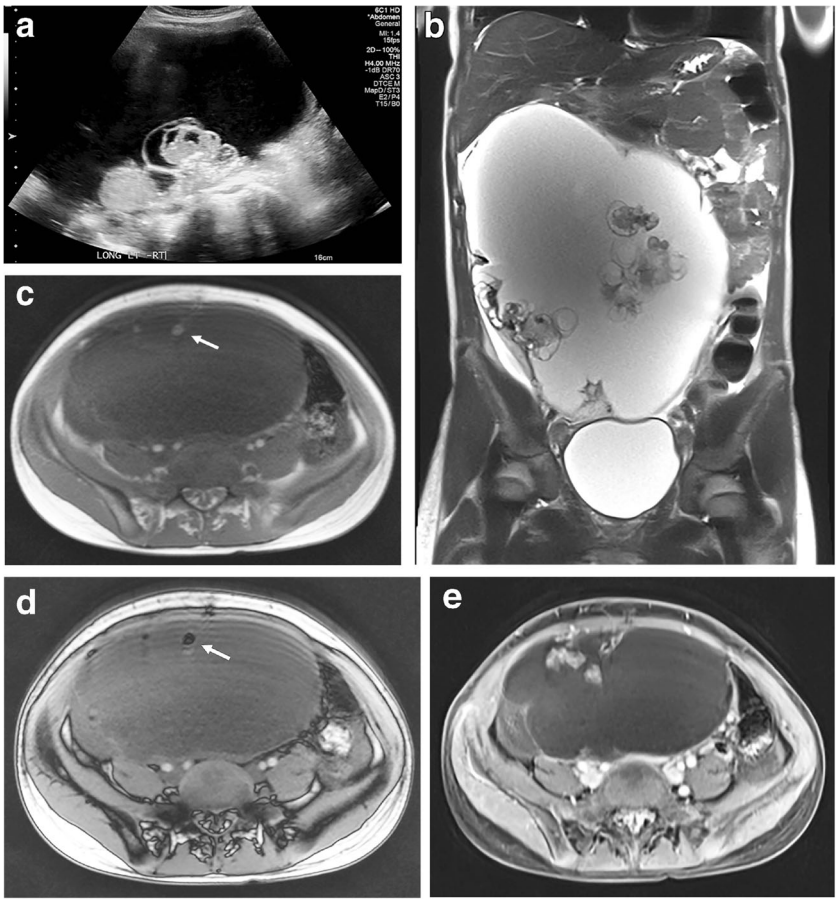

Fig. 13 Immature teratoma in a 12-year-old girl presenting with a 3-month history of increasing abdominal girth and mild abdominal pain. **a** Longitudinal ultrasound image through the pelvis shows a predominantly cystic mass with a mixed solid and cystic mural nodule. **b** Coronal T2-weighted MR image shows a large predominately cystic mass. **e** Axial contrast-enhanced 3-D T1-weighted gradient recalled echo MR image shows enhancing solid foci. Pathology was consistent with an immature teratoma. **c** Axial in-phase MR image through the mass shows foci of T1 hyperintensity (*arrow*). **d** Axial opposed-phase MR image shows loss of signal in these foci (*arrow*) of T1 hyperintensity, consistent with fat.

syndrome variant 45XO/46XY [48]. People with the *WT-1*-related disorders Frasier and Denys-Drash syndromes (both 46XY with gonadal dysgenesis) might also develop gonadoblastoma [49]. The risk is reported to be higher in people with Frasier syndrome (37–47%) than in those with Denys-Drash syndrome (4%) [50–52]. A review of 74 cases of gonadoblastoma revealed coexisting malignant germ cell tumors in 17 people, most commonly dysgerminoma [53].

Literature on the imaging appearance of gonadoblastoma is limited. Gonadoblastoma can be small and difficult to detect by ultrasound and MRI [54]. When macroscopic, it might appear as a solid ovarian mass with calcification [55, 56].

Sex cord–stromal tumors

The sex cord and stromal tumors arise from sex cord cells (Sertoli cells and granulosa cells) and stromal cells (theca cells, fibroblasts and Leydig cells) and comprise 9–18% of pediatric ovarian neoplasms [5–7]. Juvenile granulosa cell tumor and Sertoli-Leydig cell tumor are the more common sex cord neoplasms in children [57, 58]. Other less frequent subtypes include the benign entities sclerosing stromal tumor, fibroma and thecoma.

Juvenile granulosa cell tumor

Juvenile granulosa cell tumor is a malignant pure sex cord tumor predominantly occurring in people younger than 30 years. The largest series to date (125 patients) found 44% occurring in the first decade and 34% occurring in the second decade [15]. Juvenile granulosa cell tumor is a hormonally active estrogen-producing tumor; pre-menarchal females present with signs of precocious puberty, including vaginal bleeding, breast development, axillary and pubic hair, and somatic growth. Post-menarchal patients can present with menorrhagia or amenorrhea. There have also been reports of virilization [59]. Granulosa cells produce inhibin, and serum inhibin B levels might be positive. The majority of cases (>90%) are International Federation of Gynecology and Obstetrics (FIGO) Stage IA and are treated with oophorectomy.

On gross pathology these are large solid tumors with cystic spaces (mean tumor diameter 12.5 cm) [15]. Correspondingly, on ultrasound, juvenile granulosa cell

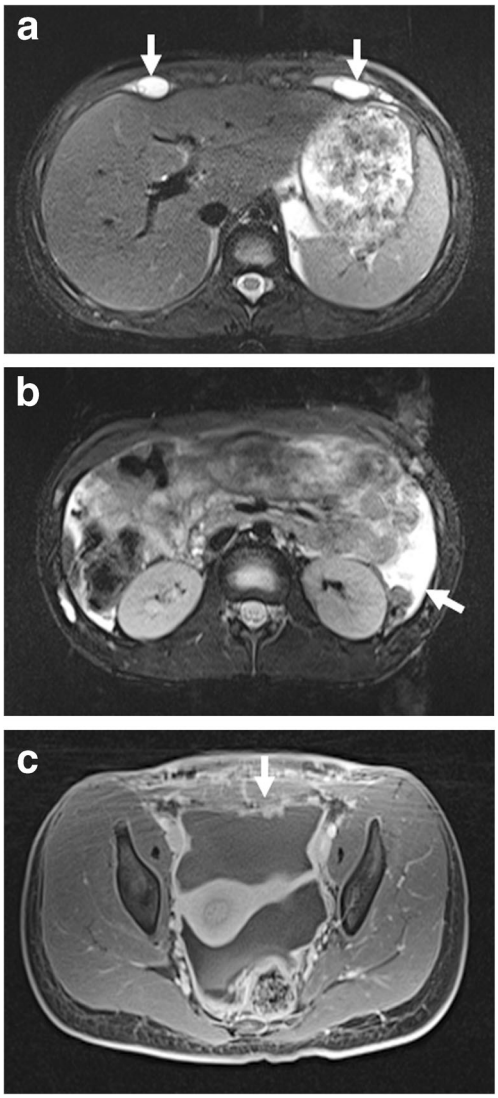

Fig. 14 Gliomatosis peritonei in a 12-year-old girl with a history of immature teratoma. **a** Axial fat-suppressed T2-weighted MR image shows lobulated T2 hyperintense foci (*arrows*) within the peritoneal cavity. **b** Additional axial fat-suppressed T2-weighted MR image shows right ascites (*arrow*) in the left upper quadrant. **c** Axial contrast-enhanced 3-D T1-weighted gradient recalled echo MR image shows nodular foci of peritoneal enhancement and ascites. Pathology revealed mature glial tissue, consistent with gliomatosis peritonei

tumor might appear as a predominantly solid lesion with cystic spaces, or a predominantly cystic lesion with solid foci (Fig. 18) [60]. Cystic spaces can be hemorrhagic, appearing as T1-hyperintense non-enhancing foci with fluid–fluid levels on MRI (Fig. 19) [60]. In 8% of cases the tumor ruptures. Three percent of cases are bilateral.

Although a definitive link between enchondromatoses syndromes and juvenile granulosa cell tumor has not been established, juvenile granulosa cell tumors have been described in association with Maffucci syndrome and Ollier disease in several case reports and in a larger series of juvenile granulosa cell tumors [8, 15, 61, 62].

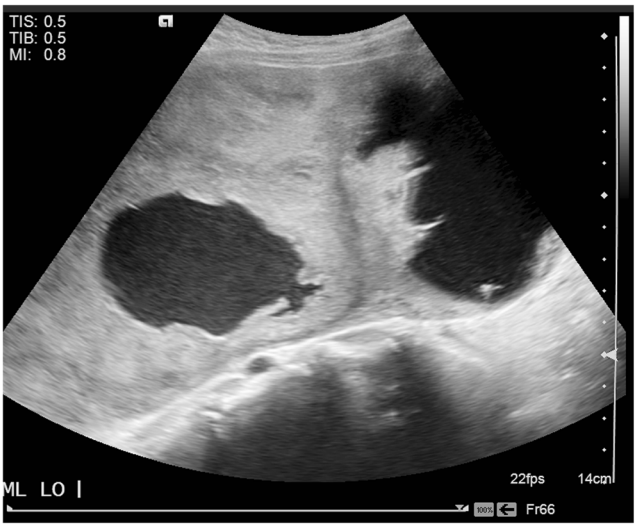

Fig. 15 Dysgerminoma in an 11-year-old girl presenting with firm palpable abdominal mass and elevated β-human chorionic gonadotropin and lactate dehydrogenase. Transverse ultrasound image shows a large predominantly solid lesion with intervening cystic foci

Sertoli-Leydig cell tumor

Sertoli-Leydig cell tumor is a malignant mixed sex cord-stromal tumor. It is histologically heterogeneous, ranging from well to poorly differentiated. Heterologous elements are present in up to 20% of cases, most commonly mucinous gastrointestinal epithelium [63]. Rarely, AFP is elevated in tumors with heterologous hepatocyte elements [4, 63]. In a review of 207 patients, Young and Scully [64] found that most tumors (46%) occur in patients ages 11–20 years, 23% occur in patients ages 21–30 years, and 6% occur in patients younger than 11 years. Sertoli-Leydig cell tumor is hormonally active, and 90% of patients present with symptoms of virilization including primary or secondary amenorrhea and hirsutism [64]. Rarely, Sertoli-Leydig cell tumor is associated with estrogen effects. Prognosis is contingent upon staging at diagnosis and the degree of histological differentiation [65]. About 54–90% of tumors are well-differentiated or moderately well-differentiated and FIGO Stage IA at the time of diagnosis [64, 65]. Higher relapse rates are reported in poorly differentiated tumors and tumors with heterologous elements [65]. In a series of 44 children with Sertoli-Leydig cell tumor, Schneider et al. [65] reported an 85% overall survival after a median of 62 months.

Sertoli-Leydig cell tumor can be solid, solid and cystic, or predominantly cystic (Fig. 20) [66]. CT and MRI show a solid enhancing mass with cystic spaces. Foci of T2 hypointensity might be present, correlating to fibrous stroma.

As stated, moderately and poorly differentiated Sertoli-Leydig cell tumor have a high association with DICER1 syndrome. The importance of this association cannot be overstated. In 22 people with germline *DICER1* gene mutation and Sertoli-Leydig cell tumor, Schultz et al. [9] found that 3 people had additional metachronous Sertoli-Leydig cell

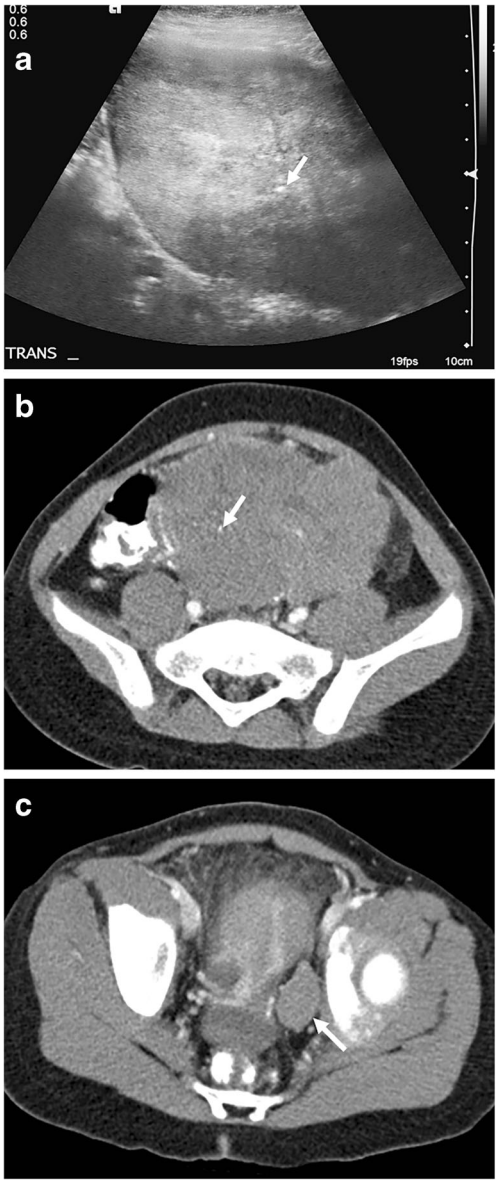

Fig. 16 Dysgerminoma in a 6-year-old girl referred from her primary care physician for possible splenomegaly. **a** Transverse ultrasound image through the mid-abdomen shows a solid mass with speckled calcifications (*arrow*). **b** Axial contrast-enhanced CT scan of the abdomen shows a solid mass with speckled calcifications (*arrow*) and regions of necrosis, arising from the right ovary. **c** Additional axial contrast-enhanced CT image through the pelvis shows a mass in the contralateral ovary (*arrow*). Pathology was consistent with a dysgerminoma

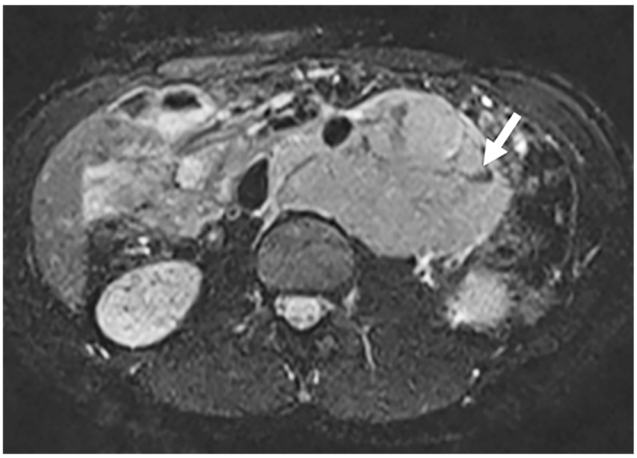

Fig. 17 MRI in a 13-year girl with a history of dysgerminoma, presenting with newly elevated β-human chorionic gonadotrophin and lactate dehydrogenase. Axial fat-suppressed T2-weighted image through the abdomen shows a typical appearance of dysgerminoma: T2-hypointense retroperitoneal mass with hypointense bands (*arrow*) representing fibrovascular septa

tumor, 4 reported well-differentiated thyroid cancer, 1 developed embryonal rhabdomyosarcoma, and the offspring of 2 people were diagnosed with Type I pleuropulmonary blastoma.

Sex cord tumor with annular tubules

According to the WHO 2014 classification of ovarian tumors, sex cord tumor with annular tubules is a pure sex cord tumor with morphologic features of both a granulosa cell tumor and a Sertoli tumor. Slightly fewer than half of patients are ≤18 years of age at presentation [8]. It is an estrogen-producing tumor, and people present with symptoms such as precocious puberty, menorrhagia and amenorrhea [67, 68]. As in juvenile granulosa cell tumor, serum inhibin B levels can be elevated [69].

When first described by Scully [69] in 1970, it was noted that 6 of the 13 cases developed in people with Peutz-Jeghers syndrome. This association was confirmed by Young et al. [67], who found that 36% of 74 cases developed in people with Peutz-Jeghers syndrome. Tumor characteristics are different in the setting of Peutz-Jeghers syndrome; sex cord tumor with annular tubules tumors in these patients are small (<3 cm) and bilateral with associated calcification. In people without Peutz-Jeghers syndrome, these tumors are unilateral and large (up to 20 cm) without calcifications [68]. Tumors in people with Peutz-Jeghers syndrome are benign, whereas tumors in non-syndromic patients have low-grade malignant potential [4].

Surface epithelial neoplasms

Unlike in adults, in whom surface epithelial neoplasms are the most common ovarian tumors, these tumors are rare in children and far less common than germ cell tumors. These tumors might be graded as benign, borderline or low-malignant potential with nuclear atypia and increased mitotic activity but without stromal invasion [70], or malignant. They are further characterized

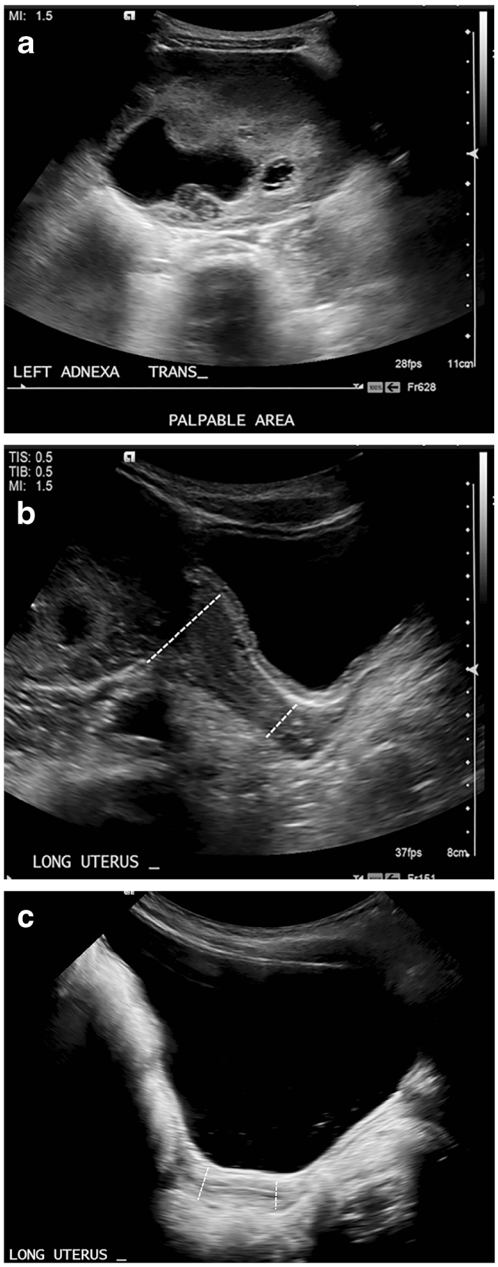

Fig. 18 Juvenile granulosa cell tumor in a 5-year-old girl presenting with a palpable abdominal mass on physical exam. **a** Transverse ultrasound (US) image through the pelvis shows a predominately solid mass with intervening cystic foci. **b** Longitudinal US image through pelvis shows an increased fundal-to-cervical ratio (*lines*), consistent with a hormonally stimulated uterus. Following an oophorectomy, pathology revealed juvenile granulosa cell tumor. **c** Postoperative longitudinal ultrasound image shows a normal pre-pubertal uterus

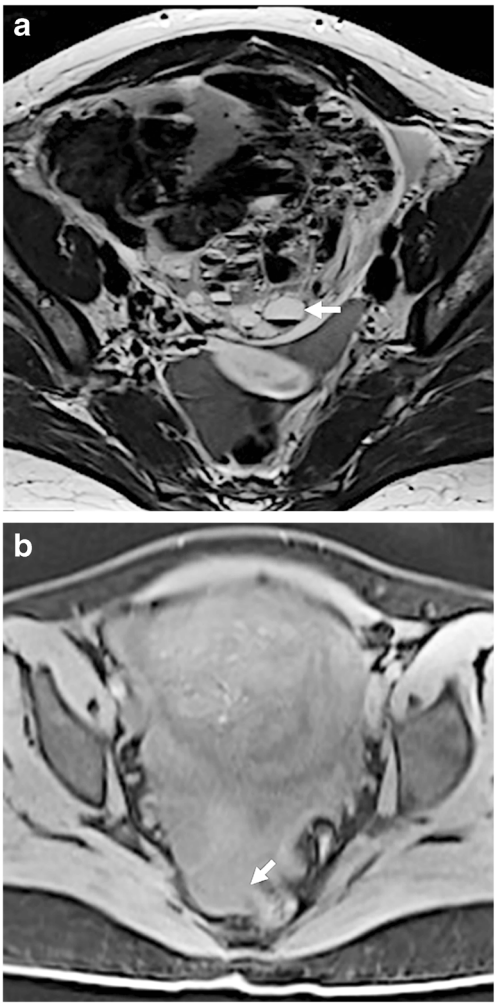

Fig. 19 Juvenile granulosa cell tumor in an 18-year-old woman who presented to the emergency room with acute-onset abdominal pain. **a** Axial T2-weighted MR image of the pelvis shows a multi-cystic mass, with fluid–fluid levels (*arrow*) likely secondary to layering blood products. **b** Axial 3-D T1-weighted gradient recalled echo MR image shows T1-hyperintense fluid in the cul-de-sac concerning for hemorrhage and tumor rupture. Intraoperative findings included torsion and tumor rupture

as serous, mucinous, clear cell, endometrioid, Brenner and mixed seromucinous subtypes. In children, pediatric surface epithelial neoplasms are usually benign (47–58%) or of low malignant potential (21–38%) [71, 72]. Of the benign lesions, serous cystadenoma is the most common. There is a near equal distribution of serous and mucinous borderline ovarian tumors. The malignant subtype is rare in children (<5%) and usually low-grade, in distinction to the high-grade malignancies commonly occurring in adults [71]. These tumors are all treated with cystectomy or oophorectomy. Recurrence of serous and mucinous cystadenoma is rare but can occur in the ipsilateral ovary. Following salpingo-oopherectomy, recurrence rates of borderline ovarian tumors is reported to be 7.7% [73].

On all modalities, serous cystadenomas are usually large, unilocular cystic masses, typically without septations (Fig. 21). Mucinous cystadenoma might appear as a multiloculated cystic mass. Borderline lesions might have papillary projections.

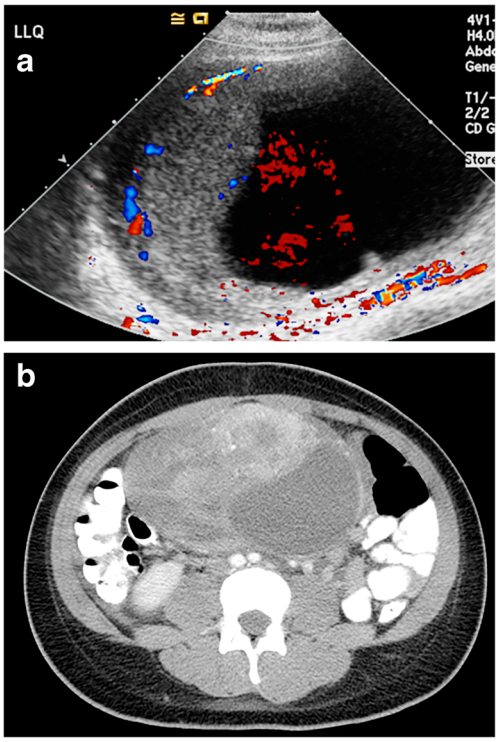

Fig. 20 Sertoli-Leydig cell tumor in a 14-year-old girl presenting with virilization. **a** Longitudinal color Doppler ultrasound image of the left lower quadrant shows a solid mass with cystic spaces. **b** Axial contrast-enhanced CT image through the pelvis also shows an enhancing solid mass with a large cystic space

Miscellaneous: Small cell carcinoma of the ovary, hypercalcemic type

Small cell carcinoma of the ovary, hypercalcemic type, is a rare, aggressive, malignant ovarian neoplasm that is histologically similar to malignant rhabdoid tumor and might in fact represent a malignant rhabdoid tumor of the ovary. As many as 62% of cases present with hypercalcemia [74]. Most cases occur between the second and fourth decades of life. Of the 150 patients analyzed by Young et al. [74], 43% had Stage III disease. Similarly, Callegaro-Filho et al. [75] reported that 49% percent of their cohort of 47 patients had Stage III disease. Prognosis is poor, with a median overall survival of 14.9 months [75].

As in other ovarian malignancies, ultrasound demonstrates a solid mass with cystic spaces [76]. On CT or MRI, it appears as a solid enhancing mass. Cystic and hemorrhagic foci might also be present.

Recent evidence indicates that small cell carcinoma of the ovary, hypercalcemic type, is highly associated with germline or somatic mutations in the *SMARCA4* gene [77]. Germline mutations in *SMARCA4* have also been implicated in rhabdoid tumor predisposition syndrome 2 [8]. It has been recommended that people with small cell carcinoma of the ovary, hypercalcemic type, be referred for genetic counseling [78].

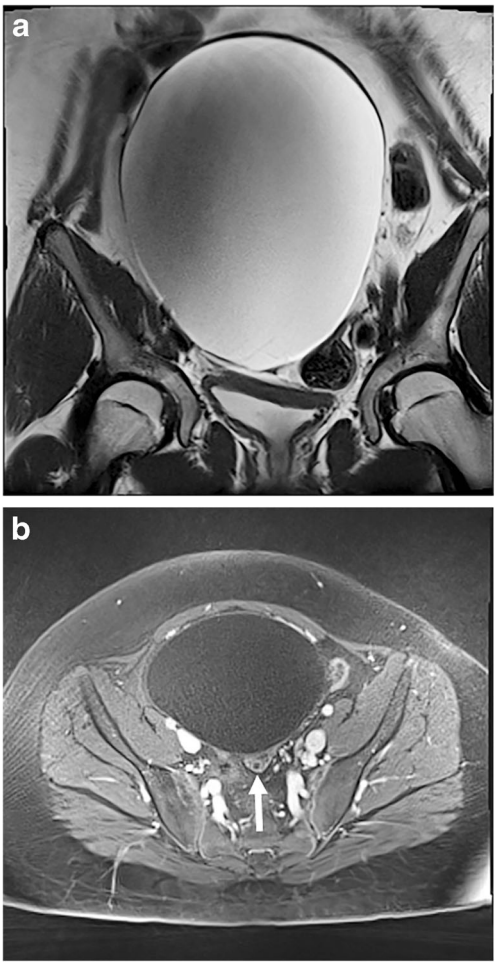

Fig. 21 MRI of a serous cystadenoma in a 13-year-old girl. **a** Coronal T2-weighted image of the pelvis shows a large unilocular T2-hyperintense mass. **b** Contrast-enhanced axial 3-D T1-weighted gradient recalled echo image shows that the mass is arising from the right ovary (*arrow*). No papillary projections were noted within the mass

Conclusion

Imaging of ovarian neoplasms in children is nonspecific. Malignancy should be suspected when a lesion measures greater than 8–10 cm and contains solid components. Elevated tumor markers, virilization and precocious puberty are clinical clues that suggest a malignant diagnosis. When an ovarian lesion is detected, careful attention to the contralateral ovary is warranted. By recognizing that an ovarian tumor might be the sign of an underlying cancer predisposition syndrome, especially when a Sertoli-Leydig cell tumor is encountered, radiologists can impact future surveillance for a child, the family and future generations.

Compliance with ethical standards

Conflicts of interest None

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