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Acute abdominal and pelvic pain in pregnancy: ESUR recommendations

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Abstract Acute abdominal pain in pregnancy presents diagnostic and therapeutic challenges. Standard imaging techniques need to be adapted to reduce harm to the fetus from X-rays due to their teratogenic and carcinogenic potential. Ultrasound remains the primary imaging investigation of the pregnant abdomen. Magnetic resonance imaging (MRI) has been shown to be useful in the diagnosis of gynaecological and obstetric problems during pregnancy and in the setting of acute abdomen during pregnancy. MRI overcomes some of the limitations of ultrasound, mainly the size of the gravid uterus. MRI poses theoretical risks to the fetus and care must be taken to minimise these with the avoidance of contrast agents. This article reviews the evolving imaging and clinical literature on appropriate investigation of acute abdominal and pelvic pain during established intrauterine pregnancy, addressing its common causes. Guidelines based on the current literature and on the accumulated clinico-radiological experience of the European Society of Urogenital Radiology (ESUR) working group are proposed for imaging these suspected conditions.

Key Points

- *Ultrasound and MRI are the preferred investigations for abdominal pain during pregnancy.*
- *Ultrasound remains the primary imaging investigation because of availability and portability.*
- *MRI helps differentiate causes of abdominopelvic pain when ultrasound is inconclusive.*
- *If MRI cannot be performed, low-dose CT may be necessary.*
- *Following severe trauma, CT cannot be delayed because of radiation concerns.*

Keywords Acute abdominal pain · Pregnancy · Guidelines · Ultrasound · Magnetic resonance

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Introduction

Acute abdominal pain in pregnancy presents diagnostic and therapeutic challenges [1, 2]. A wide variety of diseases—including disorders of the obstetric, genitourinary, gastrointestinal, hepatobiliary and vascular systems—may present with pain during pregnancy [2, 3]. The diagnosis is confounded by several common features of normal pregnancy including non-specific pain, nausea and vomiting. Clinical examination is more difficult and there is displacement of abdominal and pelvic structures by the gravid uterus [4–7]. Leukocytosis is a normal finding in pregnancy and levels of C-reactive protein are higher than in non-pregnant women [2].

Prompt diagnosis and treatment are essential for the well-being of the mother and the fetus, and imaging is commonly

requested to clarify the clinical picture and expedite diagnosis. Given the established risks to the fetus from radiation exposure, ultrasound and magnetic resonance imaging (MRI) are the strongly preferred imaging investigations [8–10].

Ultrasound is widely used as the initial diagnostic imaging technique because of its availability, portability and lack of ionising radiation [8, 11, 12]. It often elucidates the cause of abdominal pain, particularly for obstetric or gynaecological abnormalities. However, evaluation of the bowel, pancreas, ureter, and mesenteric vasculature may be limited on ultrasound because of altered body habitus, small field of view and the presence of interfering overlying structures. Air within the bowel loops displaced cranially by the uterus can limit evaluation of the mesenteric vessels and pancreas; furthermore, the origin of these displaced loops is more difficult to evaluate.

An increasing number of studies have shown that MRI is valuable in evaluating specific causes of abdominal and pelvic pain in pregnancy and is the preferred investigation when ultrasound is inconclusive owing to the lack of ionising radiation [13–19]. The aim of this work was to develop guidelines for the appropriate imaging of acute abdominal and pelvic pain in established intrauterine pregnancy based on a detailed literature review and consensus expert opinion from the Female Pelvic Imaging Subcommittee of the European Society of Urogenital Radiology (ESUR).

Process

The guidelines were developed by consensus and based on expert opinion and following a review of current practice among members of the Female Pelvic Imaging Subcommittee of the ESUR. After reviewing the literature, one author (G.M.) designed a questionnaire regarding imaging of pregnant patients presenting with acute abdominal and pelvic pain. A questionnaire based on a critique of the available scientific evidence was circulated among all the members of the Female Pelvic Imaging Subcommittee. This questionnaire evaluated what imaging investigations were used by the members in pregnant patients presenting with acute abdominal and pelvic pain, the clinical indications and the diagnostic protocols.

A first draft of the guidelines based on the data from 12 returned forms was discussed at subcommittee meetings in 2012, where all the members discussed their judgments during a face-to-face meeting. The consensus method combined all available scientific evidence with the collective judgment of experts to yield a statement regarding the appropriateness of a specific question.

The proposal was circulated before the European Congress of Radiology (ECR) 2013 in order to prepare final recommendations to be approved at the subcommittee meeting during ECR 2013. All the members agreed on the clinical indications and on the protocol proposed.

Safety considerations

Ultrasound and MRI are the imaging investigations of choice because of the lack of ionising radiation. If CT is required then the radiation dose is kept to a minimum. MRI contrast medium is not routinely given.

Ultrasound

There are no documented adverse effects on the developing human fetus from diagnostic ultrasound [20]. The US Food and Drug Administration (FDA) proposed an upper limit of 720 mW/cm^2 for spatial-peak temporal average intensity for obstetric ultrasound [20]. Doppler ultrasound can produce such high intensities and therefore time exposure should be limited to the minimum necessary for clinical diagnosis and acoustic output should also be limited to the lowest level possible [20].

MR imaging

There is no scientific evidence of risk to the human fetus from MR imaging during pregnancy. MR imaging at 1.5 T or lower magnetic field strength has been used to evaluate diseases in pregnancy for over 20 years without any documented harmful effects [21]. Therefore the statement issued in 1991 by the Safety Committee of the Society of Magnetic Resonance Imaging that “MR imaging may be used in pregnant patients … if the examination provides important information that would otherwise require exposure to ionising radiation” is still valid today [21–24].

The American College of Radiology (ACR) stated that MRI is a useful problem-solving tool in the evaluation of pelvic pain in pregnant women and, when available, MR is preferred to CT because it does not employ ionising radiation.

Pregnant women should be informed that, to date, there has been no evidence that the use of clinical MR imaging during pregnancy has produced deleterious effects. However, because of active organogenesis in the first trimester the absolute safety of MR imaging during this period is difficult to establish. MR imaging is best avoided unless the potential benefits outweigh the theoretical risks. This statement refers to machines in clinical use at 1.5 T or less.

The safety of MR at 3 T has not yet been proven. However, to our knowledge, no published human studies have documented any adverse effect on children exposed in utero to higher magnetic fields, such as 3 T; in addition, studies in animals exposed to supranormal field strengths and exposure times have found no increase in the rate of teratogenic events or chromosomal deletions [25].

Available clinical and experimental evidence provides reassurance that there is no significant risk of acoustic injury to the fetus. Indeed, the level of acoustic noise, which can reach

up to 98 dB, is dampened by the amniotic fluid by up to 30 dB [23, 26].

Possible concerns about the thermophysiological responses of the fetus exposed to MR imaging should be tempered by knowledge that manufacturers currently set limits for the specific absorption rates for each pulse sequence to ensure that the body temperature increase is less than 0.5 °C [27].

Given the known association between gadolinium contrast agents and nephrogenic systemic fibrosis (NSF), concerns have been raised regarding the use of gadolinium in pregnancy [28–30]. Gadolinium-based contrast agents cross the placenta and are excreted by the fetal kidneys into the amniotic fluid where the gadolinium undergoes a time-dependent dissociation from its chelate [29]. Despite the lack of any evidence of adverse effects after MR studies in the human fetus [30], gadolinium-based contrast agents are classified as category C drugs by the FDA and should only be administered to a pregnant patient "if the potential benefit justifies the potential risk to the fetus and using the smallest dose of the most stable gadolinium agent" [31].

Computed tomography

A careful risk–benefit analysis is warranted before performing CT in pregnancy [32–34].

Epidemiological studies suggest that exposure to a total cumulative dose of ionising radiation of less than 50 mGy is not associated with a significant risk of fetal teratogenesis. Moreover, the teratogenic effects of ionising radiation (including microcephaly, microphthalmia, mental retardation, growth restriction, cataracts and behavioural defects) only occur following exposure between the 2nd and 20th week of gestation [32]. Most diagnostic CT examinations, even performed in multiple phases, result in a fetal dose of well below 50 mGy. The radiation exposure to the fetus from a typical CT study of the maternal pelvis is variable and depends on the gestational age and CT parameters, ranging from around 25 to 80 mGy: within this range and up to around 100 mGy evidence shows that the teratogenic effects of CT are extremely unlikely [34].

However, in utero exposure to radiation from CT and diagnostic radiography is associated with increased risk of childhood cancer. Based on the very low baseline risk of 1 in 2,000, the odds of dying of childhood cancer doubles to 2 in 2,000 after exposure to 50 mGy. According to the Oxford Survey of Childhood Cancers, the risk is higher if exposure occurs during the first trimester rather than during the second or third trimesters, with relative risks of 3.19, 1.29 and 1.30, respectively [34, 35].

In summary, although the risks of teratogenesis are minimal, fetal exposure from pelvic CT within the range of 20 to 50 mGy increases the risk of fatal childhood cancer by a factor of 1.4 to 2 [34].

Therefore, high-dose ionising radiation examinations such as CT can only be justified in pregnant women when the study is overwhelmingly in the best health interest of the mother, i.e. there is no diagnostic alternative. The ALARA principle (As Low As Reasonably Achievable) must be adhered to and an appropriate discussion is required between clinician and radiologist regarding the risk/benefit ratio.

When CT is performed, the pregnant woman should be counselled regarding the possible increased occurrence of childhood cancers after fetal irradiation.

In regards to the use of iodinated contrast media, in vivo animal studies have failed to show the teratogenic effect from the use of these drugs in pregnancy. Direct instillation of ionic iodinated contrast medium into the amniotic cavity during amniofetography [29] was found to have the potential to produce neonatal hypothyroidism, whereas the intravascular use of non-ionic contrast media had no effect on neonatal thyroid function. ESUR guidelines state that there is no definite conclusion on the risks of intravascular iodinated contrast medium use in human pregnancies and recommend that it should be administered only if absolutely necessary and after informed consent has been obtained [31]; furthermore, neonatal screening for hypothyroidism should follow for all neonates whose mothers received iodinated contrast medium during pregnancy [36].

Recommendations regarding imaging protocols in pregnancy

MR imaging

Patient preparation

Pregnant patients are informed about MR imaging safety issues, and informed written consent is obtained before each study. The principles guiding the use of MR imaging in pregnancy are to avoid any potential harm even where there are no firm data indicating this has occurred previously. Therefore examinations should be avoided in the first trimester, intravenous gadolinium agents should be avoided and examinations should be performed using the minimum thermal and acoustic energy dissipated in the fetus to achieve a clinically useful diagnosis [35]. With those considerations in mind, all necessary diagnostic options should be available to the radiologist when it is judged that use of MR imaging is essential for the mother's and thus the fetus's well-being.

MR examinations for maternal abdominal pain usually follow ultrasound assessment, further clinical review and availability of the basic emergent laboratory test results, e.g. full blood count, serum C-reactive protein and amylase levels. There is usually a 'working diagnosis' and the MR examination is usually focussed on a particular region of the abdomen

and an organ or organ system based on these findings. Key clinical features such as vaginal bleeding, jaundice or haematuria clearly focus the investigation and in most situations MR imaging acts as a problem-solving tool within that abdominal area or system. It is rare to perform an 'abdominal pain' protocol.

Technique considerations in pregnancy are about flexibility and consideration of the patient's needs. There is no specific patient preparation. Extra time needs be allowed in the imaging schedule. These examinations are best supervised by the reporting radiologist to ensure that the diagnostic information is obtained with the minimum of sequences and/or energy dissipation. If a patient is uncomfortable or feels faint lying supine within the MR gantry (especially in the third trimester), imaging with the patient in the lateral decubitus position is appropriate (decreasing the pressure on the inferior vena cava) [8].

Protocol

Whilst a phased-array coil provides a superior signal-to-noise ratio, in larger patients and towards the end of pregnancy, a body coil may be preferable.

A comprehensive multiplanar imaging protocol is used to evaluate the most common causes of abdominal pain (Table 1). The field of view for the examination extends from the dome of the liver superiorly through the symphysis pubis inferiorly. The protocol includes breath hold multiplanar T2-weighted sequences based on the half-Fourier reconstruction technique (half-Fourier RARE or single-shot fast spin-echo), and the balanced gradient-echo sequences (FIESTA, true FISP); axial and sagittal T1-weighted gradient-recalled echo (GRE) sequences; and axial and sagittal diffusion sequence. The time required for this protocol is 20 min.

In addition to these routine sequences, axial two-dimensional (2D) time-of-flight (TOF) images (TR/TE of 25 ms/minimum) can be obtained from the renal veins to the symphysis pubis to screen for a venous clot. If MR cholangiopancreatography (MRCP) or MR urography is indicated, a thin-slice, three-dimensional (3D), heavily T2-weighted FSE sequence can be performed.

Intravenous gadolinium contrast medium is not routinely administered; on review of the unenhanced images, the radiologist may consider the administration of intravenous contrast medium only in selected cases. If contrast-enhanced imaging is needed, 2D or 3D GRE T1-weighted images can be acquired after administration of gadolinium at a dose of 0.1 mmol/kg. In this case a macrocyclic gadolinium chelate should be used because it is the most stable, is caged in a molecular ring and only very small amounts of gadolinium are retained within the tissues [28, 31].

Computed tomography

Pregnant patients are informed about CT imaging safety issues, and informed written consent is obtained before each study.

CT is the first-line investigation of the common suspected causes of abdominal pain in the non-pregnant abdomen, e.g. appendicitis and ureteric colic. However, a careful risk–benefit analysis is warranted before performing CT in pregnancy. Alternative methods that do not use ionising radiation such as ultrasound and MRI should be considered.

Table 1 MR protocol for the abdomen and pelvis during pregnancy

Parameter	Balanced gradient-echo sequence (FIESTA, true FISP, BSSFP)		T2 half-Fourier sequence (HASTE)		T1 3D FS gradient echo sequence	DWI
	Axial	Coronal/sagittal	Axial/axial FS	Coronal/sagittal	Axial/sagittal	Axial/sagittal
Repetition time/echo time (ms)	4.3/2.2	4.3/2.2	1,000/90	1,000/90	4.1/1.1	3,200/75
Flip angle (°)	50	50	150	150	10	10
Field of view (mm)	320–400	320–400	320–400	320–400	320–400	320–400
Matrix	256×224	256×224	256×224	256×224	256×224	256×192
Parallel imaging factor	2	2	2	2	3	2
Section thickness (mm)	5	5	4	4	2.5	10
Intersection gap (mm)	0	0	0	0	0	0
NEX	1	1	1	1	1	6
Receiver bandwidth	125	125	62.50	62.50	62.50	1,930

Diffusion-weighted MR images were acquired with *b* values of 50, 400 and 800 s/mm^2

FIESTA fast imaging employing steady-state acquisition, *FISP* fast imaging with steady-state precession, *BSSFP* balanced steady-state free precession, *HASTE* half-Fourier single-shot turbo spin-echo, *FS* fat saturated

CT is the investigation of choice when there is a life-threatening situation and a rapid diagnosis is required. The great value of CT is that it can cover many organ systems and large patient volumes rapidly. Thus with hypovolaemic blunt or penetrating trauma or severe sepsis when a variety of sites of injury or infection need to be evaluated, CT is a primary tool.

The ALARA principle dictates that a low-radiation-dose technique should be adopted but this and the gravid abdominal circumference result in increased image noise.

Causes of abdominal pain in pregnancy

Part I: Obstetric causes

Placental abruption

Placental abruption is the premature separation of a normally implanted placenta with a reported perinatal mortality and morbidity rate up to 10–25 % [37, 38]; it should be suspected in the presence of vaginal bleeding or abdominal pain or both, a history of trauma or an otherwise unexplained preterm labour. Ultrasound findings of placental abruption refer to the presence of a haematoma that can be between the myometrium and chorionic membrane, posterior or anterior to the placenta [38]. The overall diagnostic performance of ultrasound in the diagnosis of abruption is poor [39, 40], with 25–50 % of haematomas, mostly retroplacental, remaining undetected [41–44] either because the echotexture of recent haemorrhage is similar to that of the adjacent placenta [39] or because of the small dimensions of the haematoma, as most clots resulting from chronic abruption may drain through the cervix [44]. The most important ultrasound criteria for placenta abruption (sensitivity 80 %, specificity 92 %) are the detection of pre-/retroplacental collections, evidence of marginal subchorionic or intra-amniotic haematomas, increased placental thickness (>5 cm) and jelly-like movements of the chorionic plate [42, 44]. It must be remembered that as lesions detected by ultrasound are relatively large (and thus severe) ultrasound-diagnosed abruptions have greater morbidity and mortality [45].

MR imaging is accurate in detecting placental abruption [46, 47]. MR sensitivity and specificity can reach 100 % using diffusion-weighted (DW) sequences [48]; comparable results can be obtained by T1-weighted sequences, whereas T2-weighted and balanced gradient-echo sequences have shown less reliability [46–48] (Fig. 1).

The capability of MRI to date haemorrhage on the basis of the paramagnetic effects of methaemoglobin [49] may help to identify hyperacute abruptions with signs of acute bleeding that are prone to progressing to higher clinical grades, with possible onset of fetal distress or maternal decompensation [48]. It has been reported that a specific training in obstetric MRI is not required for the diagnosis of intrauterine clot as the interobserver agreement is excellent, including among non-expert readers [47]. In traumatised patients who undergo CT, a systematic assessment of the placenta rules out abruption with a reported sensitivity of 100 %; however, specificity is greatly improved by the knowledge of the appearance of the normal placenta and greatly decreases without specific training [50].

Placental adhesive disorders

Placental adhesive disorders (PAD) include different degrees of abnormally adherent placenta, with placental villi attached to the myometrium (accreta), invading the myometrium (increta), or penetrating up to the uterine serosa (percreta) [51]. The overall incidence of PAD is 1 in 2,000 pregnancies, with a rapid increase mainly attributed to the rising rate of caesarean sections and other uterine surgery [52, 53].

When using ultrasound, the presence of lacunae within the placenta is the most predictive ultrasound sign (sensitivity of 79 %, positive predictive value (PPV) of 92 %) of PAD [54, 55]; other evidence includes loss of the hypoechoic placental-myometrium interface, thinning or disruption of the hyperechoic interface between uterine serosa and bladder and the presence of focal exophytic masses [56].

Doppler, either 2D or 3D, increases the accuracy of ultrasound in distinguishing normal decidua basalis vessels from those that pass through the myometrium, with demonstration of numerous coherent vessels involving the whole uterine serosa/bladder junction, detection of hypervascularity, evidence of inseparable cotyledonal and intervillous circulations, chaotic branching and detour vessels [57, 58].

Several studies have compared the accuracy and effectiveness of ultrasound versus MRI in the detection of PAD [59–64].

Two recent comparative studies have shown ultrasound and MRI to be comparable: in the first study 15 out of 32 women had accreta (sensitivity 93 % versus 80 % and specificity 71 % versus 65 % for ultrasound versus MRI) [65]; in the second study 12 out of 50 women had accreta and MRI and Doppler showed no difference in detection ($P=0.74$), although MRI was better at detecting the depth of infiltration in cases of placenta accreta ($P<0.001$) [63].

Many authors recommend a two-stage approach to optimising diagnostic yield, beginning with ultrasound in patients with clinical risk factors and then proceeding to MR imaging for equivocal cases especially in patients with posterior placenta and previous myomectomy [59, 61, 62, 64, 65]. Other authors have suggested that MR imaging can better define areas of abnormal placentation, modify levels of invasion, ultimately change surgical management and should be used routinely [60, 66, 67].

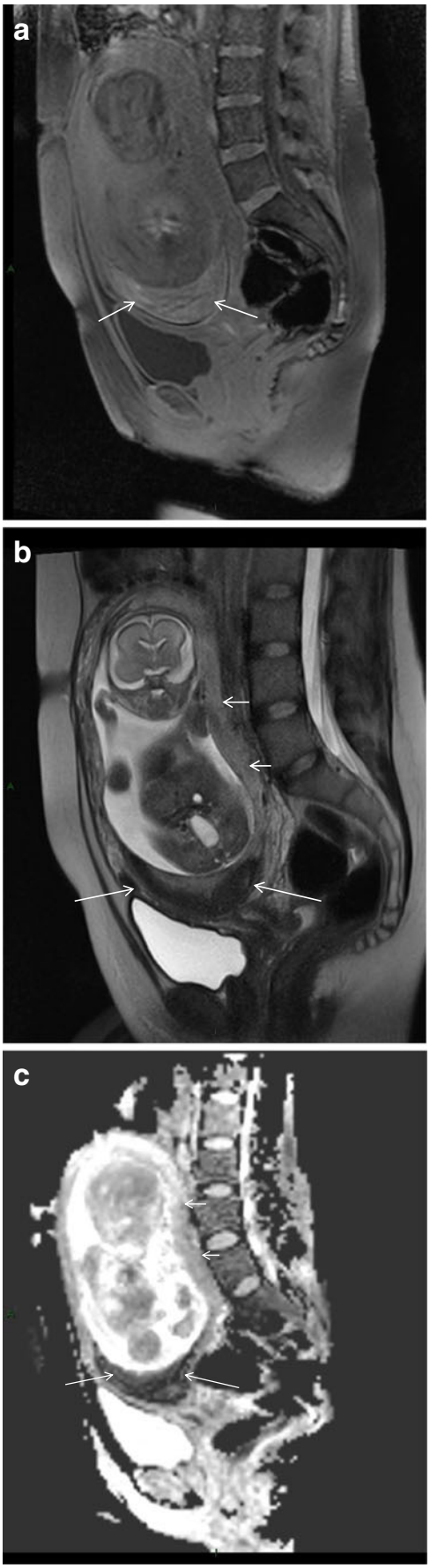

Fig. 1 A 31-year-old woman at 28 weeks' gestation with acute pelvic pain, vaginal bleeding and transvaginal greyscale ultrasound suggestive of the presence of placenta praevia, with no evidence of haematoma. **a** Sagittal T1-weighted fat-saturated gradient-echo image shows the hyperintense subchorionic haematoma (*arrows*) located above the internal os. **b** Sagittal T2-weighted half-Fourier single-shot turbo spin-echo (HASTE) sequence shows the intrauterine clot with hypo- and hyperintense areas (*long arrows*). **c** Sagittal diffusion-weighted apparent diffusion coefficient (ADC) map shows the low signal of the haematoma (*long arrows*). The signal intensity characteristics are suggestive of hyperacute haematoma. The placenta (*short arrows* in **b** and **c**) is normally situated and has normal signal intensity

Uterine rupture

Uterine rupture (complete separation of the uterine layers with rupture of intra-amniotic contents and extravasation of fetal parts into the peritoneal cavity) [68] most commonly originates from dehiscence of a caesarean section scar or is related to trauma to an intact uterus; an otherwise intact uterus only rarely ruptures [69]. When uterine rupture occurs intrapartum, abdominopelvic ultrasound shows a bulky empty uterus with an anterior hypo/anechogenic line corresponding to the uterine tear, the fetus and placenta in the abdominal cavity and increased intraperitoneal fluid [70, 71]. Ultrasound may help to select a safe trial of vaginal birth after Caesarean section (VBAC) [72, 73]; uterine scar rupture can be predicted by visualising a full lower uterine segment thickness of less than 3.5 mm [74] or a hypoechoic myometrial layer of less than 2.0 mm [75–77]. MRI allows clear visualisation of the uterine wall; therefore, it helps to diagnose both ante-partum uterine rupture in patients with indeterminate ultrasound evidence, showing the tear itself [78] and other uterine wall defects including uterine dehiscence (separation of the myometrium with preservation of the overlying peritoneum and internal fetal membranes) [79] and uterine sacculation (uterine wall ballooning because of a functional weakening of the myometrium) (Fig. 2) [19].

Part II: Gynaecological causes

Common gynaecological causes of pain during pregnancy include complications related to adnexal masses, which are either pre-existing but undergo complications such as torsion due to displacement by the gravid uterus or from new physiological adnexal masses resulting from the pregnancy [12, 15, 80]. Both ovarian masses and mobile uterine leiomyomas have a higher incidence of torsion during pregnancy [81–84].

Adnexal masses

Adnexal masses are found in 1–2 % of pregnancies and may present with acute abdominal pain due to haemorrhage or torsion [83]. Most masses can be accurately assessed by ultrasound

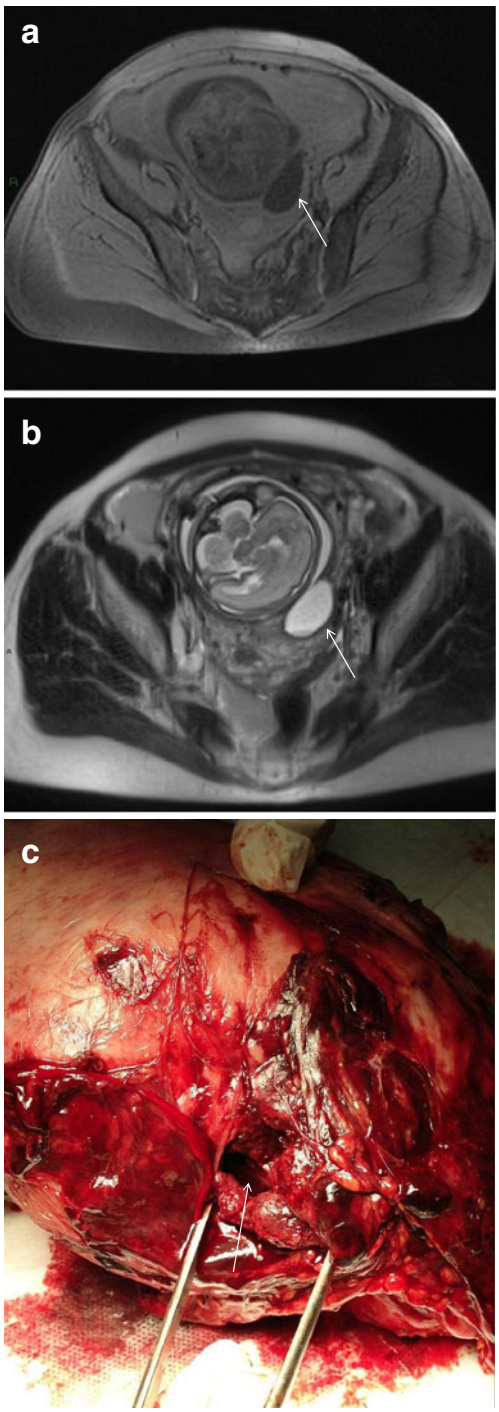

Fig. 2 A 34-year-old woman, primipara with a history of three previous myomectomies, was admitted at 26 weeks' gestation presenting with vomiting, acute abdominal pain and tenderness in the upper quadrants. Abdominal ultrasound revealed only intraperitoneal fluid representative of haemoperitoneum. **a** Axial T2-weighted HASTE and T1-weighted fat-saturated gradient recalled echo (GRE) (**b**) sequences showed posterior extravasation of amniotic fluid into a hernial sac (*arrows*), that contains a small fluid level; these findings are suggestive of a sealed uterine rupture. **c** Emergency laparotomy showed a 3-cm bleeding irregular uterine rupture (*arrow*)

[81, 82]. However, MR imaging can provide further characterisation, particularly for evaluating their haemorrhagic content, evident as high signal intensity on T1-weighted sequences with no signal loss on fat suppression. It can identify an exophytic/pedunculated leiomyoma by showing its stalk, a band of tissue with associated bridging vessels connecting the mass to the uterus [85].

Ovarian torsion

Ovarian torsion is the most serious complication of benign ovarian lesions and occurs in 1 in 800 pregnancies [86]. Torsion may occur at any time during pregnancy but has a peak incidence at between 6 and 14 weeks' gestation [86]. It may occur in an otherwise normal ovary, mostly on the right-hand side [86].

A combination of greyscale ultrasound imaging and colour Doppler findings is the preferred imaging technique for the diagnosis of ovarian torsion. It should be suspected in any pregnant woman with an ovarian mass who has severe pain. The likelihood is increased if there has been an increase in the size or change in the appearance of a mass discovered earlier in pregnancy. Additional findings include a twisted vascular pedicle, pelvic free fluid and reduced or absent intralesional flow. Arterial waveforms may be detectable when the torsion is of low grade and has caused only obstruction of the ovarian veins, or when one pedicle of a duplicated blood supply to the ovary is preserved [87]. The arterial waveform may be of high impedance, then dampened and later absent [88].

MRI should be performed after inconclusive ultrasound. It has a specificity and negative predictive value for the diagnosis of ovarian torsion of 100 % and 83 %, respectively, in small case series [89]. On T2-weighted sequences, the enlarged ovary appears initially hyperintense owing to stromal oedema and the ovarian follicles are pushed to a peripheral location. On T1-weighted sequences there may be evidence of haemorrhage. Later there is a heterogeneous pattern due to the presence of haemorrhage and necrosis. Ancillary findings include a thickened thrombosed pedicle, a blood-filled Fallopian tube (haematosalpinx) and a haemoperitoneum.

Although it would be normal to administer gadolinium to show absent perfusion in the non-pregnant patient, this should be avoided in pregnancy.

Uterine leiomyoma

One in 500 pregnant women experience acute abdominal pain with uterine tenderness and possibly low-grade fever owing to leiomyoma-related complications, mostly the result of haemorrhagic infarction [90].

Leiomyomas may increase in size during the first trimester as a response to increased oestrogen synthesis [90]. During the ultrasound examination, the symptomatic patient complains of point tenderness when the probe is placed over the offending leiomyoma. Ultrasound features

in acute haemorrhagic infarction (red degeneration), include heterogeneous or hyperechoic lesions. Later, leiomyomas may have anechoic components resulting from cystic necrosis, which allows confirmation of the diagnosis [11, 12].

In about 5 % of cases leiomyomas (especially when necrotic) may mimic pathological pelvic conditions, including uterine variants and pregnancy-related conditions [84, 91].

MRI can be a useful diagnostic adjunct when leiomyomas are located deep in the pelvis or in the posterior myometrium because these ones may be more difficult to evaluate with ultrasound and point tenderness cannot be elicited. Again high and heterogeneous signal intensities on T1-weighted and T2-weighted sequences, respectively, reflect haemorrhage and oedema/necrosis within the leiomyoma [92].

Part III: Non-obstetric and gynaecological causes

Urolithiasis

Urolithiasis and urinary tract infection are the most common causes of abdominopelvic pain in pregnancy and urolithiasis is the most common non-obstetric indication for hospitalisation [93].

Ultrasound is the first imaging test for suspected urolithiasis in pregnancy, despite its substantial limitations and a reported sensitivity as low as 34 % [94, 95]. False negatives are rare and due to obstruction without dilatation, but false positives are common because of the dilatation of the collecting system that occurs physiologically in pregnancy.

Ultrasound can identify stones within the renal pelvis but direct demonstration of ureteral calculi is difficult owing to the gravid uterus. Stones at the ureterovesical junction may be detected using transvaginal ultrasound. Doppler techniques have been evaluated as an adjunct [95, 96].

Colour Doppler may show the presence of the twinkling artefact at the level of the stone even at sites where differentiation of the hyperechoic stone from surrounding hyperechoic tissues may be difficult [97]. Comparison between sides of the resistive index (RI) from intrarenal Doppler waveforms can be helpful in patients with acute obstruction showing a difference of at least 0.04 in RI of intrarenal arteries between the symptomatic kidney and the contralateral one [94]. Colour Doppler can also be used to detect the passage of urine at the ureterovesical junction: the so-called ureteral jet. In the non-pregnant abdomen, absence of this sign on the symptomatic side has a very high sensitivity and specificity for obstruction [95]. However, its diagnostic value is hampered as ureteral jets may be absent in 15 % of asymptomatic pregnant women. Possible false-positive results can be decreased by imaging patients in the contralateral decubitus position; this manoeuvre reduces the degree of physiological dilatation [96].

The value of intravenous urography (IVU) in pregnancy is limited, owing to the confounding physiological hydroureter and superimposed gravid uterus. The fetal osseous structures can obscure visualisation of ureteral calculi. Moreover, the radiation dose is not significantly lower than that from the renal stone CT protocol [98].

Magnetic resonance urography (MRU) using heavily T2-weighted 'water' images is a valuable examination, differentiating physiological urinary tract dilatation from abnormal dilatation related to urolithiasis [99]. With calculus obstruction there is renal enlargement and perinephric oedema not seen with physiological dilatation. In the latter, there is smooth tapering of the middle third of the ureter because of the mass effect between the uterus and adjacent retroperitoneal musculature. When the stone is lodged in the lower ureter a standing column of dilated ureter is seen below this physiological constriction. High-resolution T2-weighted images through the point of calibre change can identify the calculus responsible [100].

MRI is helpful in demonstrating complications such as pyelonephritis that are visualised as an enlarged oedematous kidney. Areas of focal pyelonephritis have lower signal intensity on T2-weighted and restricted proton diffusion on the DW images (Fig. 3) [101].

In unresolved cases, CT remains a reliable technique for depicting obstructing urinary tract calculi in pregnant women. The average estimated fetal dose, using a low-dose CT technique, was 7 mGy, i.e. below the 50 mGy limit above which there is a statistically higher risk of teratogenesis [22, 34, 102].

Appendicitis

Appendicitis occurs in about 1 in 1,500 pregnancies and is a difficult diagnosis in pregnancy owing to variable appendiceal position and difficulty with clinical examination of the gravid abdomen [2–4, 102, 103].

Ultrasound is the technique of choice for investigating suspected appendicitis, using the same parameter set for non-pregnant patients, including visualisation of a blind-ending, dilated (>6–7 mm in diameter) aperistaltic and non-compressible tubular structure arising from the caecum [104, 105]. It must be recognised that the caecum and appendix may be displaced by the gravid uterus. Ultrasound of the appendix is a highly operator-dependent examination and can be limited by the pregnant body habitus, especially in the later stages of gestation [105].

Its diagnostic performance is variable with reported sensitivity and specificity values ranging from 50 to 100 % and from 33 to 92 %, respectively [104, 105]. The appendix is visualised in a minority of patients especially if elevated or retrocaecal. The overall diameters of the appendix may overlap in normal and pathological cases [106]. Other diagnostic features with a dilated appendix include appendiceal wall thickening (>2 mm), appendicoliths and surrounding hyperechoic inflamed fat or hypoechoic fluid) [105].

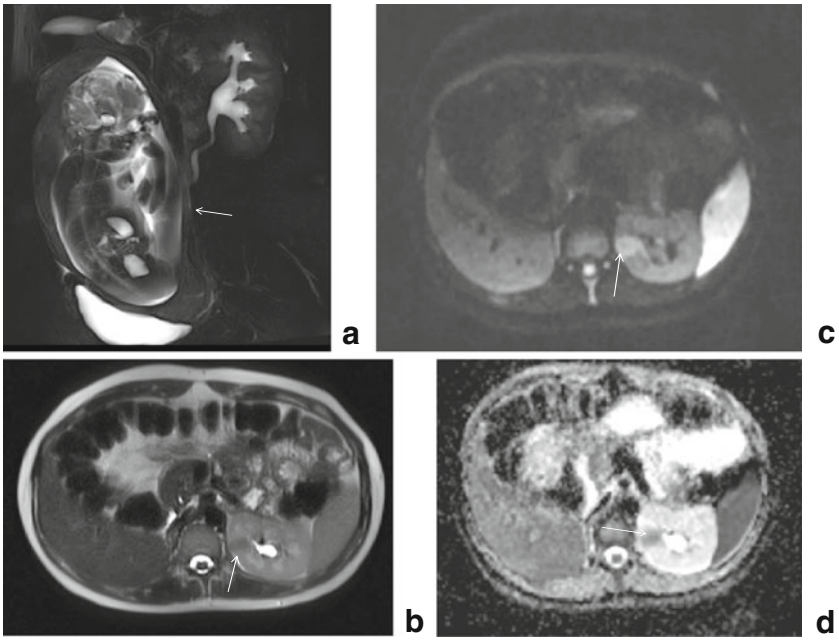

Fig. 3 A 27-year-old woman, primipara, was admitted at 33 weeks' gestation presenting with acute abdominal pain and fever. Ultrasound showed mild left hydronephrosis. **a** MR urography (MRU) shows smooth tapering of the middle third of the ureter (*arrow*) because of the mass effect between the uterus and the adjacent retroperitoneal musculature. This finding is characteristic of physiological urinary tract dilatation. **b** Axial T2-weighted HASTE sequence shows a focal area of low signal intensity (*arrow*) of the left kidney with restricted proton diffusion on the DW image (*b* value=800) (**c**) and on the ADC map (**d**) (*arrow*) indicative of pyelonephritis

If neither a normal nor an abnormal appendix can be confidently identified on ultrasound and there is no clear alternative diagnosis identifiable on ultrasound, MRI should be considered [107]. Findings on MR imaging include a distended appendix with a hyperintense lumen on T2-weighed images. In addition, periappendiceal inflammation is best appreciated on fat-suppressed T2-weighted images as bands of high signal intensity. Moreover the appendiceal wall may be slightly hyperintense on T2-weighted imaging, indicating the presence of oedema.

It has an overall reported sensitivity of 100 % and specificity of 94 % [108–111].

Oral contrast medium in not widely used in MRI clinical practice [10, 17–19, 112], despite the evidence that the use of negative intraluminal agent following a specific protocol [108] grants the highest rate of identification of normal appendix. In suspected appendicitis in pregnancy, intravenous gadolinium is not used.

If MR imaging cannot be performed, because of absolute contraindications or is not available, CT is an alternative. The risks of misdiagnosis without accurate imaging outweigh the small potential risk of ionising radiation. Positive CT findings are the same as in non-pregnant patients with high sensitivity and specificity of 92 % and 99 %, respectively [113].

Bowel obstruction

In the gravid patient, ultrasound is the first choice in the evaluation of bowel conditions other than appendicitis. Bowel obstruction in pregnancy is fairly uncommon (1 per 2,500 to 1 per 3,500 pregnancies). It is usually due to adhesions (60–70 %), less commonly due to volvulus (≈25 %) [1]. In long-standing or high-grade obstruction, ultrasound may show dilated loops of bowel with fluid levels and aperistalsis, but depiction of the point or cause of bowel obstruction usually remains undetermined.

Magnetic resonance studies for bowel obstruction, performed with the use of multiplanar T2-weighted single-shot fast spin-echo (SSFSE) imaging, do not have extensive validation, but can accurately depict the site of small bowel obstruction in approximately 70 % of cases (Fig. 4) [19, 114–116].

One-third of women with inflammatory bowel disease (IBD) will relapse during pregnancy, usually from cessation or reduction of necessary therapy.

There is strong evidence for using MRI to detect intra- and extraluminal abnormalities in the abdomen, pelvis and perineum [114–116]. A bowel wall thickness greater than 3 mm has been reported to have a sensitivity of 83–91 % and a specificity of 86–100 % for Crohn's disease [116]. Submucosal oedema in the small bowel produces increased signal intensity on T2-weighted images and is seen with active inflammation [116].

Acute cholecystitis

Gall bladder disease is the second most common non-obstetric emergency, after appendicitis, requiring surgery during pregnancy. Symptomatic biliary tract disease in pregnancy is uncommon, but gallstones are more prevalent in pregnancy (up to 12 %) [103, 117].

A dedicated right upper quadrant ultrasound is the most appropriate initial imaging study for the evaluation of acute cholecystitis in pregnancy [118]. However, there is a potential

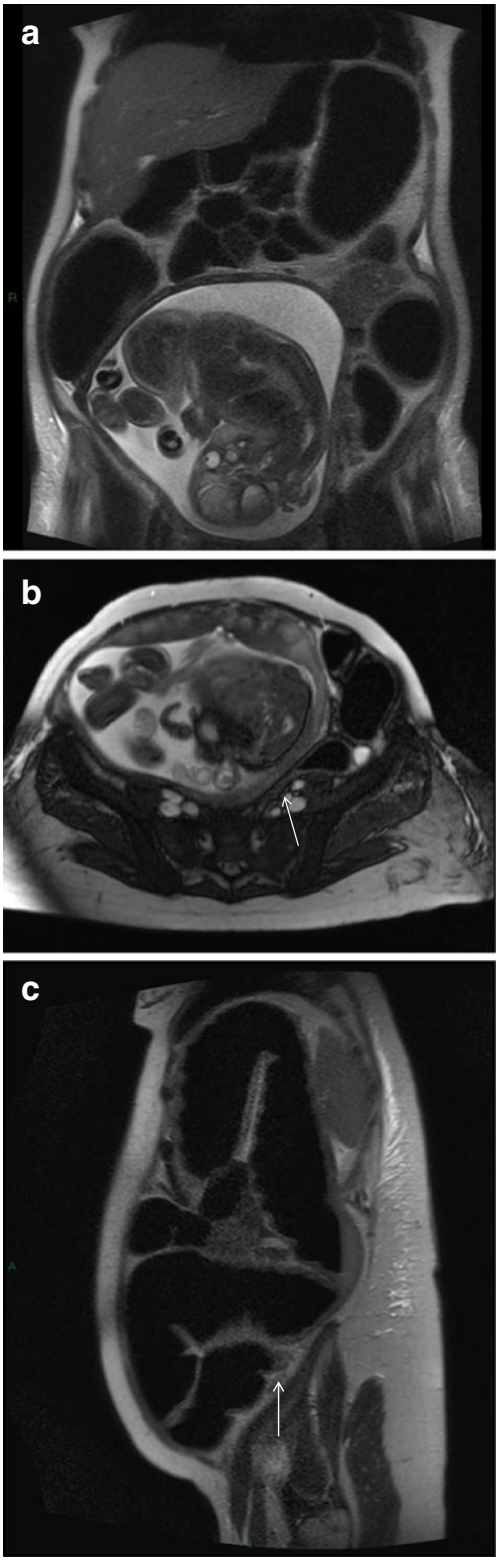

Fig. 4 A 35-year-old woman was admitted at 30 weeks' gestation presenting with vomiting, acute abdominal pain and tenderness in the lower quadrants; ultrasound was unremarkable. **a** Coronal T2-weighted HASTE sequence shows dilation of colon and small bowel loops. Axial true fast imaging with steady-state precession (FISP) (**b**) and sagittal T2-weighted HASTE (**c**) sequences show a focal transition point at the level of the sigmoid with "beak" pattern (*arrow*), indicative of close loop obstruction. Laparotomy revealed a sigmoid volvulus

for reduced image quality because of changes in the body habitus and displaced bowel. Ultrasound findings of acute cholecystitis include gall bladder distension (>5 cm diameter), wall thickening (>3 mm), pericholecystic fluid and wall hyperaemia. Irregular linear echoes within the lumen, which represent fibrinous exudates and sloughing of the mucosa, may be seen with more severe cases and may reflect gangrenous cholecystitis [119].

The pressure of the ultrasound probe over the inflamed gall bladder may elicit tenderness over the inflamed gall bladder, as does probe palpation of a tender uterine fibroid or appendix mass. However, a positive ultrasound Murphy's sign can be difficult to elicit during late pregnancy [119].

MRCP is the most appropriate second-line imaging test to evaluate biliary disease . It is highly sensitive (98 %) and specific (94 %) for the detection of biliary disease and is more sensitive than ultrasound for the detection of choledocholithiasis [120].

The use of MRCP in pregnant patients with biliary ductal dilatation seen by ultrasound has been shown to obviate further exploration with endoscopic retrograde cholangiopancreatography (ERCP) [13]. MRCP should be used in pregnant patients when the benefit outweighs the risk, regardless of gestational age.

ERCP is an effective procedure for the imaging and treatment of choledocholithiasis, but it is invasive, requires sedation, and exposes the patient and fetus to ionising radiation. ERCP also has potential risks, including pancreatitis, perforation and haemorrhage [121]. Although studies have shown that ERCP can be safely performed in pregnant women, in light of its associated risks, its use is best restricted to instances when therapeutic intervention has been planned on the basis of sonographic or MRCP results.

Hepatic diseases

Two hepatic complications unique to pregnancy that can present with acute abdominal pain are the HELLP syndrome (Haemolysis, Elevated Liver enzymes and Low Platelet count), often associated with pre-eclampsia, and acute fatty liver of pregnancy (AFLP), a rare but potentially fatal complication of the third trimester of pregnancy [122–125].

Patients with or suspected of having HELLP syndrome with right upper quadrant or shoulder tip pain should undergo ultrasound because a haematoma can develop beneath Glisson's capsule [126]. Subsequent rupture into the peritoneal cavity may result in sudden hypotension and shock. Depending on the clinical presentation, ultrasound, CT or

Table 2 Key MR signs of the different diseases causing acute abdominopelvic pain during pregnancy

	T2-weighted (HASTE, ssFSE)	T2-weighted FS (HASTE, ssFSE)	Steady state sequences (true FISP, FIESTA, balanced FFE)	T1-weighted	DWI	Others
Placenta abruption	Placenta haematoma		Placenta haematoma	Placenta haematoma	Placenta haematoma	
Placenta percreta	Dark intraplacental bands		Focal outward bulge in placenta into adjacent tissues or organs			
Uterine rupture	Myometrial defect		Myometrial defect			
Urolithiasis		Renal oedema Perirenal fluid	Renal enlargement	Renal enlargement	Renal abscess	MR urography: obstruction level
Appendicitis	Distended appendix with hyperintense lumen	Periappendiceal fluid and inflammation	Distended appendix with hyperintense lumen		Abdominal abscess	
Bowel obstruction	Distended loops with transition point	Submucosal wall oedema	Distended loops with transition point	Distended loops with transition point		
Hepatobiliary causes		Pancreatic oedema and perirenal fluid		Pancreatic oedema		MRCP: biliary lithiasis
Venus thrombosis cause	Heterogeneous material in the vein		Dark clot in the vein			TOF: dark clot in the vein

MRI can be used to assess the patient [127–129]. Ultrasound can show intra- and extrahepatic haematomas and fluid collections. Contrast-enhanced CT may show a bleeding point in the arterial phase in unstable patients but the use of MRI has increased in recent years as a problem-solving tool in the stable patient [129].

With AFLP, the issue is to determine the cause of acute liver dysfunction and/or jaundice. Ultrasound of the liver may show increased heterogeneity and echogenicity of the hepatic echotexture from fatty infiltration. MR examinations performed with T1-weighted dual gradient-echo in-phase (IP) and out-of-phase (OOP) sequences can readily depict hepatic steatosis by

Table 3 The value of ultrasound, MRI and CT and how they help in pregnancy

	Ultrasound	MRI	CT
Placenta abruption	Low sensitivity up to 50 %, mostly due to retroplacental haematoma	Accurate up to 100 % (T1-weighted and DWI in detecting haematoma); consider after negative ultrasound findings	Indicated in a trauma setting
Placenta percreta	Accurate up to 90 %; power Doppler is used	Accurate up to 100 %. Indicated after inconclusive ultrasound, especially in case of posterior placenta and previous myomectomy	Not indicated
Uterine rupture	Accurate up to 88 %	Useful in differentiating dehiscence and rupture	Indicated in a trauma setting
Adnexal mass	Accurate up to 90 %	Useful for further characterisation	Not indicated
Ovarian torsion	Accurate in 93 %	MRI should be performed after inconclusive ultrasound	Not indicated
Uterine leiomyoma	Accurate	Useful when they are located deep in the pelvis or in the posterior myometrium	Not indicated
Urolithiasis	Low sensitivity up to 35 %	Accurate in differentiating physiological from pathological urinary dilation and in detecting pyelonephritis	Indicated in depicting obstructing urinary tract calculi
Appendicitis	Accurate from 50 to 90 %; less in the third trimester	MRI should be performed after inconclusive ultrasound	Alternative if MRI is not available
Bowel obstruction	Low accuracy	MRI should be performed after inconclusive ultrasound	Alternative if MRI is not available
Hepatobiliary	Accurate	MRI should be performed after inconclusive ultrasound	Alternative if MR is not available
Pelvic vein thrombosis	Sensitivity of 55 %; power Doppler is used	Greater sensitivity and specificity. Use time-of-flight MR angiography	Not indicated

showing loss of hepatic signal intensity on the (OOP) images [129].

Pancreatitis

Pancreatitis is an infrequent condition in pregnancy and is most commonly caused by cholelithiasis [3]. The approach to imaging pregnant patients with pancreatitis differs from that of the non-pregnant patient. In pregnancy, gallstones are the most common cause of pancreatitis because pregnancy promotes the formation of sludge and stones within the gall bladder owing to increased cholesterol synthesis, bile stasis and decreased gall bladder contraction.

During pregnancy, ultrasound is used initially to search for the cause and complications of pancreatitis namely choledocholithiasis and pseudocyst formation. If ultrasound is normal or indeterminate, MR imaging including MRCP should be performed [15, 16].

Venous thromboembolic disease

Both venous stasis and hypercoagulability place pregnant patients at increased risk of venous thrombosis. Venous stasis begins in the first trimester and peaks at around 36 weeks' gestation and is likely due to a combination of progesterone-induced venodilation, caval and pelvic venous compression by the gravid uterus, and pulsatile compression of the left iliac vein by the right iliac artery. The hypercoagulable state of pregnancy results as the haemostatic system is progressively activated to prepare the patient for the haemorrhagic challenges of delivery [5, 15].

Most venous thromboembolic events occur in the lower extremities. However, pregnant patients are also at increased risk of pelvic, hepatic (Budd–Chiari syndrome), mesenteric and gonadal venous thrombosis that may result in acute pain [3, 7]. These events fall within the wider differential diagnosis of pain in pregnancy and usually undergo generic investigation depending on the severity and localisation of pain and whether the patient is stable or hypotensive.

Acute trauma

Trauma affects 6–7 % of pregnancies in the USA and is the leading cause of non-obstetric maternal death, with 0.3 % of pregnant women reported to require hospital admission because of trauma [130].

Complications of blunt or penetrating trauma to the pregnant abdomen include uterine events such as placental abruption and rupture; maternal injury or demise; and, consequentially, direct fetal injury or demise [131, 132]. Thus timely and effective evaluation after traumatic injury is critical for the well-being of both the mother and fetus.

In the haemodynamically stable patient, ultrasound should be performed as part of the initial assessment to evaluate for free intraperitoneal haemorrhage. Splenic rupture is the most common cause of free intraperitoneal haemorrhage. There is a wide range of reported accuracies for ultrasound in the detection of traumatic injury, 61–83 % sensitivity and 94–100 % specificity [132].

If ultrasound shows free intraperitoneal haemorrhage or unexplained free fluid, contrast-enhanced CT including arterial phase imaging should be considered. Death of the mother is the most common cause of fetal death in these patients. This is one of the circumstances in which CT should not be delayed because of radiation concerns regarding the fetus (Tables 2 and 3).

Conclusion

Determining the cause of acute abdominal and pelvic pain in pregnant women can be difficult because of the multiple confounding factors found in normal pregnancy.

Pelvic ultrasound is the preferred primary imaging investigation but it may be of limited value due to the altered body habitus, a small field of view and the presence of interfering overlying structures. MR imaging is extremely accurate in identifying both obstetric and non-obstetric causes and should be used when ultrasound findings are non-diagnostic or equivocal. This expert consensus statement provides clinical recommendations for the prompt and accurate diagnosis of acute abdominal and pelvic pain in pregnancy.

Synopsis and key recommendations for imaging pregnant patients with acute abdominal and pelvic pain

1. Imaging techniques
   - Ultrasound remains the primary imaging investigation because of availability and portability, but it can be limited because of altered body habitus, small field of view and the presence of interfering overlying structures.
   - MRI helps differentiate causes of abdominopelvic pain when ultrasound is inconclusive.
   - Following severe trauma, CT cannot be delayed because of radiation concerns.
2. Optimal MR protocol
   - Breath hold multiplanar T2-weighted sequences based on the half-Fourier reconstruction technique, and the balanced gradient-echo sequences and axial

and sagittal T1-weighted GRE and diffusion sequences.

3. Recommendations for clinical practice

Placental abruption MRI should be considered after negative ultrasound findings when there is high clinical suspicion and when a firm diagnosis of abruption would change clinical management.

Placenta adhesive disorders Ultrasound in patients with clinical risk factors and then proceeding to MR imaging for equivocal cases especially in patients with posterior placenta and previous myomectomy.

Uterine rupture MRI to diagnose ante-partum uterine rupture in patients with indeterminate ultrasound evidence, showing the tear itself and other uterine wall defects including uterine dehiscence.

Adnexal mass Most masses can be accurately assessed by ultrasound; however, MR imaging can provide further characterisation, particularly for evaluating their haemorrhagic content.

Leiomyoma Ultrasound is accurate in most cases. Perform MRI if any difficulty differentiating from an adnexal mass.

Ovarian torsion Magnetic resonance imaging should be performed after inconclusive ultrasound and can detect hemorrhagic infarction.

Urolithiasis Ultrasound is the first imaging test despite its substantial limitations.

Magnetic resonance urography (MRU) differentiates physiological urinary tract dilatation from abnormal dilatation related to urolithiasis.

In unresolved cases, CT remains a reliable technique for depicting obstructing urinary tract calculi in pregnant women.

Appendicitis Ultrasound can be limited by the pregnant body habitus, especially in the later stages of gestation. MR should be performed in case of inconclusive ultrasound.

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