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Diagnostic value of 3D T1-weighted gradient-echo and 2D T1-weighted in-phase and out-of-phase gradient-echo sequences for appendicitis diagnosis in pregnant women

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ABSTRACT

Objectives: This study compared the diagnostic value of 3D T1-weighted (T1W) gradient-echo (GRE) and 2D T1W in-phase and out-of-phase GRE sequences for appendicitis diagnosis in pregnant women.

Material and Methods: This retrospective study included 25 pregnant patients with suspected appendicitis who underwent 1.5 Tesla abdominal magnetic resonance imaging and had definitive diagnoses. Four doctors approached four separate imaging groups: A (only T2-weighted image [T2WI] sequences), B (T2WI and 3D T1W GRE sequences), C (T2WI and T1W in-phase and out-of-phase GRE sequences), and D (T2WI, 3D T1W GRE, and T1W in-phase and out-of-phase GRE sequences). The kappa (κ) index was used to compare the appendicitis diagnostic results between groups. The diagnostic value of these sequences in the diagnosis of pregnancy appendicitis was also evaluated.

Results: Groups A and C had average consistency with definitive diagnosis (κ = 0.6), lower than Groups B and D (κ = 0.865), indicating a high definite diagnosis consistency. Groups B and D had similarly high sensitivity (80%), specificity (100%), positive predictive value (100%), negative predictive value (95.2%), and accuracy (ACC) (96%), higher than Groups A and C (60%, 95%, 75%, 90.5%, and 88%, respectively).

Conclusion: 3D T1W-GRE sequences improve appendicitis diagnosis in pregnancy compared to T2W sequences alone. Adding in and out phase GRE sequences do not increase diagnostic ACC.

Keywords: Magnetic resonance imaging, Appendicitis, Pregnancy, 3D T1-weighted gradient-echo, 2D T1W in-phase and out-of-phase gradient-echo

INTRODUCTION

Acute appendicitis is the most common cause of abdominal pain requiring emergency surgical intervention in pregnant women, with an incidence of 0.05–0.07%.[1-3] Radiology plays a crucial role in its diagnosis due to the limitations of clinical examination and other laboratory tests. While ultrasonography is considered the modality of choice in these cases, it depends on the physician's experience and is limited by the positional changes of abdominal organs during pregnancy. Magnetic resonance imaging (MRI) has been used routinely to diagnose pregnancy appendicitis for nearly two decades.

Numerous studies have shown MRI's outstanding value in this area.[4-8] Each study used a different sequence protocol. Choosing sequences with high diagnostic values is more important than taking a series of different sequences, reducing examination time and minimizing discomfort due to the poor breath-holding ability of pregnant women, especially those with high fetal weight and gestation weeks. Therefore, this study compared the diagnostic value of 3D T1-weighted (T1W) gradient-echo (GRE) and 2D T1W in-phase and out-of-phase GRE sequences for diagnosing appendicitis in pregnant women.

MATERIALS AND METHODS

Subjects

This retrospective study included 56 pregnant women with suspected appendicitis who underwent MRI at our hospital between July 2019 and August 2022. Among them, 25 underwent MRIs that met our research protocol [Table 1]. All patients with MRI-diagnosed appendicitis were operated on. Patients with non-specific MRI findings and clinical symptoms were followed for at least 2 weeks. We collected clinical information on each enrolled patient, comprising maternal age, gestation week, and white blood cell count, from the hospital's medical record archive. This study was approved by the Institutional Review Board (Ref: 2674/QĐ-ĐHYHN; dated July 13, 2021). Informed consent was waived due to the study's retrospective design, and the analyses used anonymized clinical data.

MRI method

All MRI images were collected with a Siemens 1.5 T Magnetom Essenza MRI machine (Siemens Medical Systems, Erlangen, Germany), scanning from the liver's lower border to the pelvis. The patient was supine with a coiled body. The sequences used included:

- Axial, coronal, and sagittal T2-weighted (T2W) the half Fourier acquisition single-shot turbo spin echo (HASTE)
- Axial T2W HASTE with fat saturation
- Axial 3D T1W GRE volumetric interpolated breath-hold examination with fat saturation
- Axial T1W in-phase and out-of-phase GRE imaging.

Detailed MRI image parameters are summarized in [Table 1]. The entire examination time was approximately 20 min. No cases used oral or intravenous contrast products.

Image analysis

The appendix was observed through MRI in the 25 enrolled patients, of which four had an MRI-based appendicitis diagnosis. These four patients underwent surgery and were confirmed to have appendicitis by surgery and pathology. The remaining 21 cases with no MRI-based appendicitis diagnosis were monitored clinically. Of these, one case was later diagnosed with peritonitis surgically due to ruptured appendicitis (3 days post-MRI); all others were confirmed non-appendicitis cases. Therefore, based on pathological results and clinical follow-up, this study had five appendicitis cases and 20 non-appendicitis cases.

Four radiologists with >5 years of experience in gastroenterology independently interpreted the MRI images on the INFINITT PACS system (Infinitt Healthcare, Seoul, South Korea). The radiologists were blinded to information about surgical, pathological, and clinical follow-up results. Each used a separate set of images. There were four image groups: A (only T2W sequences), B (T2W and 3D T1W GRE), C (T2W and T1W in-phase and out-of-phase GRE), and D (T2W, 3D T1W GRE, and T1W in-phase and out-of-phase GRE). Radiologists were asked to determine whether appendicitis was present based on the provided images. In a pregnant woman, the appendix, which has a double-layer wall thickness and a diameter of around 6 mm, is frequently seen on T2W image of the pelvis. The appendix's lumen sometimes showed hyposignal in the in-phase compared to the out-phase GRE image, indicating the presence of air inside the lumen [Figure 1].

The standard criteria for defining appendicitis were an increase in appendiceal size (diameter ≥7 mm) and periappendiceal fatty infiltration [Figure 2]. We considered such cases negative predictive value (NPV) for appendicitis, regardless of appendix size. In cases where there was disagreement on the diagnostic conclusion in the combined groups (B, C, and D) based on images from different sequences, the radiologists used the results based on the 3D T1W GRE sequence (for group B) and in-phase and out-

Table 1: Sequence parameters used in the research protocol.

Sequence	Breath-hold	FOV (mm)	ST/gap (mm/mm)	TR (msec)	TE (msec)	Matrix
T2W HASTE	Yes	360	4/1	800–1000	60–80	256×192
T2W HASTE+FS	Yes	360	4/1	800–1000	50–70	256×192
T1W VIBE FS	Yes	360	2.5/1	4	2	180×180
Axial IP and OP 2D T1W GRE	Yes	360	4/1	224	2–5	252×250

T2W: T2-weighted, FOV: Field of view; ST: Slide thickness, TR: Time of repetition, TE: Time of echo event, IP: In-phase, OP: Out-of-phase, GRE: Gradient echo, HASTE: Half Fourier acquisition single-shot turbo spin echo, VIBE FS: volumetric interpolated breath-hold examination with fat saturation

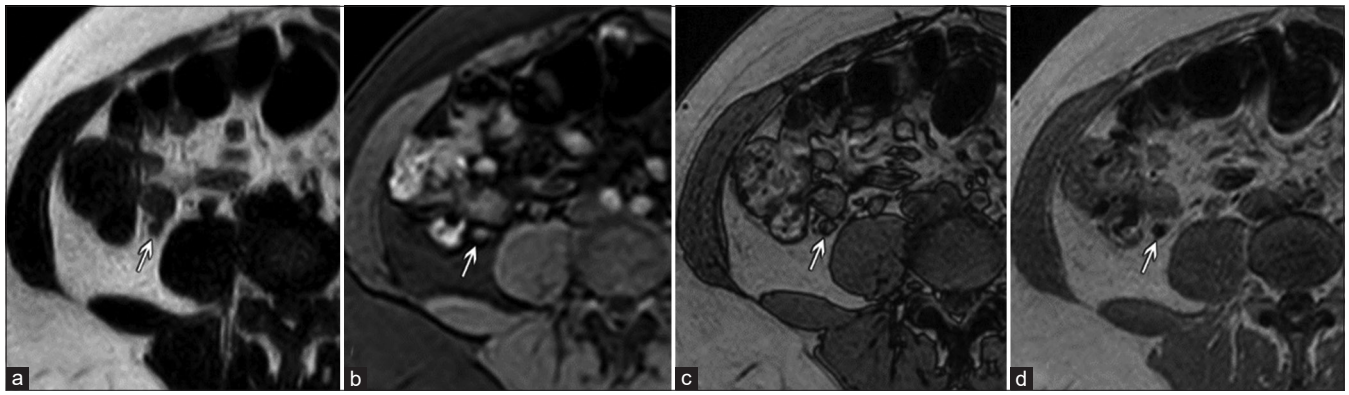

Figure 1: Normal appendix in a 28-year-old pregnant woman at 12 *week*s gestation. The appendix size was small, without surrounding infiltration on all sequences (arrow). (a) Axial T2-weighted image. (b) Axial 3D T2-weighted gradient-echo (GRE). (c) Out-of-phase GRE. (d) Axial in-phase GRE. Her final diagnosis was non-appendicitis based on clinical follow-up.

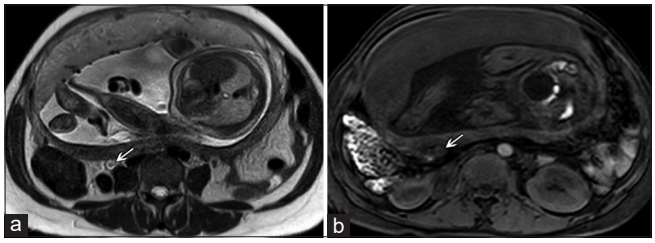

Figure 2: Appendicitis in a 41-year-old woman at 32 weeks pregnant. (a) Axial T2-weighted image shows an enlarged appendix with intraluminal fluid but unclear surrounding infiltrates (arrow). (b) Axial 3D T2-weighted gradient-echo shows an enlarged appendix with surrounding infiltrates (arrow); this case was later diagnosed with appendicitis after surgery and pathology.

of-phase GRE sequences (for Group C). For Group D, the radiologists made a majority conclusion (diagnosis from 2/3 sequences).

Statistical analysis

Data analyses were performed using SPSS v.22 (IBM Corp., Armonk, NY, USA). The patient's demographic, clinical data, and appendiceal characteristics involving maternal age, gestational age, and leukocyte count were analyzed by calculating means and percentages (with standard deviations) in appendicitis and non-appendicitis groups. The Shapiro–Wilk test was used to assess the normality of data distributions. Since the variables were non-normally distributed, they were compared using Mann–Whitney tests. Differences between two qualitative variables were assessed using Chi-squared and Fisher's exact tests. All differences with $P < 0.05$ were considered statistically significant.

Kappa (κ) statistics were used to evaluate the consensus between diagnoses in Groups A, B, C, and D with pathological and clinical follow-up results: κ = 0–0.20, poor agreement; κ = 0.21–0.40, fair agreement; κ = 0.41–0.60, moderate agreement; κ = 0.61–0.80, good agreement; and κ = 0.81–1, very good agreement.[9] Test results were considered statistically significant at $P < 0.05$.

Sensitivity (Se), specificity (Sp), accuracy (ACC), and positive (PPV) and negative (NPV) predictive values of Groups A, B, C, and D for appendicitis diagnosis during pregnancy were determined based on the following gold standard: pathological and clinical follow-up results.

RESULTS

Study population

The study population's demographic and clinical characteristics are presented in [Table 2]. The two groups did not differ significantly in maternal age and gestational weeks. However, white blood cell counts were significantly higher in the appendicitis group than in the non-appendicitis group ($P = 0.043$).

Association between MRI findings and treatment results

Groups A and C had a κ index of 0.600, representing average consistency between the group and definitive diagnoses. Groups B and D had a κ index of 0.865, higher than Groups A and C, indicating a high consistency between the group and definitive diagnoses [Table 3].

Diagnostic accuracy of MRI findings

The diagnostic values of each group are shown in [Table 4]. Groups B and D had similarly high Se, Sp, PPV, and ACC, which were all higher than for Groups A and C.

DISCUSSION

Acute appendicitis is the most common cause of non-obstetric abdominal pain requiring surgical emergency treatment

Table 2: Demographic and clinical characteristics of the study subjects.

	Non-appendicitis (*n*=20)	Appendicitis (*n*=5)	*P*
Maternal age	27.95±4.8	30.4±7.1	0.500
Gestational age	25.2±9.9	26.6±7.1	0.730
Leukocyte count	10.84±2.6	13.8±2.3	0.043*

*$P<0.05$

Table 3: Correlation between group appendicitis diagnoses and definitive diagnoses.

	Definitive diagnosis		κ	*P*
	Non-appendicitis	Appendicitis		
Group A				
Non-appendicitis	19	2	0.600	0.003
Appendicitis	1	3		
Group B				
Non-appendicitis	20	1	0.865	<0.001
Appendicitis	0	4		
Group C				
Non-appendicitis	19	2	0.600	0.003
Appendicitis	1	3		
Group D				
Non-appendicitis	20	1	0.865	<0.001
Appendicitis	0	4		

Table 4: Appendicitis diagnostic value in each group.

	Se (%)	Sp (%)	PPV (%)	NPV (%)	ACC (%)
Group A	60	95	75	90.5	88
Group B	80	100	100	95.2	96
Group C	60	95	75	90.8	88
Group D	80	100	100	95.2	96

Se: Sensitivity, Sp: Specificity, ACC: Accuracy, PPV: Positive predictive value, NPV: Negative predictive value

during pregnancy.[10,11] During pregnancy, the maternal body experiences decreased immunity, increasing steroid hormone levels. Therefore, they are more prone to infectious diseases. In addition, clinical appendicitis symptoms during pregnancy are non-specific and complicated due to natural physical and anatomical changes in the appendix's location. Consequently, diagnosing pregnancy appendicitis is challenging. The risk of complications, such as rupturing and developing peritonitis, in this population is higher than in the average population. Accurately diagnosing the appendix's inflamed condition in pregnant women early is crucial in providing them with the best treatment strategy.[12] MRI is an accepted imaging diagnosis modality for appendiceal inflammation during pregnancy.

Mean maternal age did not differ significantly between the non-appendicitis (30.4 ± 7.1 years) and appendicitis (30.4 ± 7.1 years) groups ($P = 0.500$). In addition, their gestation weeks distribution was similar ($P = 0.730$). These findings are consistent with Shin *et al.*[13] and Theilen *et al.*[14] However, Andersen and Nielsen[1] and Guttman *et al.*[10] reported that appendicitis was most common in the second trimester.

In this study, white blood cell levels were significantly higher in patients in the appendicitis group than in the non-appendicitis group, consistent with Shin *et al.*[13] and Cardall *et al.*[15] However, Mourad *et al.*[16] and Stone[17] found that high white blood cell levels were not informative for diagnosing appendicitis during pregnancy. Their appendiceal inflamed patients had white blood counts >10,000/mm³, but so did 50% (10/20) of patients with normal appendices. Pritchard and Rowland[18] found that white blood cell counts can fluctuate from 6,000 to 16,000/mm³ and even as high as 20,000–30,000/mm³ during normal pregnancy.

To the best of our knowledge, no previous study has assessed the diagnostic efficacy of 3D T1W GRE sequence and in-out phase images or the diagnostic value of in-out phase images solely in diagnosing pregnancy appendiceal inflammation. Only Jang *et al.*[19] sought to determine the diagnostic value of 3D T1W images. Our study indicates a moderate agreement between T2W image analysis alone or combined with in-out phase images of the final appendicitis diagnosis (κ = 0.600). Similarly, Jang *et al.*[19] found agreement between T2W image analysis results and pathological diagnoses (κ = 0.571), indicating good agreement. Our analyses found excellent agreement between final diagnosis and pathological findings in groups using 3D T1W images (κ = 0.865). These results are higher than those of Jang *et al.*,[19] illustrating a good within-group agreement (κ = 0.673). This disagreement between our study and Jang *et al.*[19] in using 3D T1W combined with T2W might be due to our use of 3D T1W sequences with a 2.5 mm slide thickness, while Jang *et al.*[19] used a 3 mm slide thickness. Using in-out phase images for diagnosis disagreed with MRI final diagnosis and final pathological diagnosis.

Jang *et al.*[19] showed that adding 3D T1W-GRE images to T2WI helps identify the appendix and improves diagnostic confidence compared to T2W image analysis. This study's 3D T1W-GRE images assisted and increased diagnostic ACC from 88% to 96%. However, adding in-out phase images did not add value to the diagnostic process. Adding 3D T1W GRE images to T2WI provided 80% Se, 100% Sp, 100% PPV, and 95.2% NPV. These results are consistent with Pedrosa *et al.*,[4] Vu *et al.*,[7] Duke *et al.*,[8] and Wi *et al.*[20] These studies used different protocols and had sensitivities of 50–97%, specificities of 92–100%, and accuracies of up to 96%. Our study's use of 3D T1W GRE images with a thinner slide thickness (<3 mm) could explain these differences since it increases image quality and shortens acquisition time.

Intra-appendiceal T1W hyperintensity due to fecal accumulation could be determined by reducing water content through self-absorption.[21] It accounted for 92.3% and 51.0% of T1W hyperintensity in normal appendices in Jang *et al*.[19] and Shin *et al*.,[13] respectively. In addition, during this study, we discovered that periappendiceal infiltration signs were more accessible on 3D T1W images than on T2W pictures with or without fat saturation since both water and fat show hypersignal intensity in T2W images. 3D T1W images could provide clues to distinguish true from false-positive cases due to periappendiceal fluid collection.

One case was misdiagnosed with appendicitis based on T2W images showing periappendiceal hypersignal intensity with fatty stranding without any suggestion signs in 3D T1W images. This case underwent surgical intervention with intrasurgical confirmation of the right ovarian torsion, which caused secondary fluid collection in the right iliac region. In addition to diagnosing appendicitis, the 3D T1W sequence can also aid radiologists in uncovering other abnormalities. For example, one case in our study population was diagnosed with a normal appendix using T2W images but failed to specify the leading cause of pain. The 3D T1W images showed a cystic lesion in the left iliac region with intralesional fluid, and pelvis fluid collection showed T1W hypersignal intensity. The patient underwent emergency surgical treatment, and the final result was hemorrhage ovarian cyst rupture, consistent with MRI detection.

This study had several limitations. First, since our study population was relatively small, it might only partially represent part of it. Second, in-out phase and 3D T1W images were obtained with 4 mm and 3 mm slice thicknesses, respectively. Therefore, image quality could cause differences in volume effect. Finally, differences in enrolled patient numbers in appendicitis and non-appendicitis groups might influence our results.

CONCLUSION

Our study showed that adding a 3D T1W GRE sequence to the diagnostic protocol facilitated the accurate diagnosis of appendicitis during pregnancy better than analyzing T2W images alone. Moreover, 3D T1W images played a pivotal role in diagnosing another abnormality that might cause pain during pregnancy. However, in-out phase sequences had limited value in imaging analyses for pregnancy appendicitis.

Authors' contributions

Nguyen Duy Hung and Nguyen Minh Duc contributed equally to this article as the first authors. Nguyen Duy Hung and Nguyen Minh Duc prepared, drafted, and revised the manuscript critically for important intellectual content. Nguyen Duy Hung and Nguyen Minh Duc contributed substantially to data acquisition, analysis, and interpretation. Each author gave final approval to the version of the manuscript submitted for publication and agreed to be accountable for all aspects of the work, ensuring that questions related to the ACC or integrity of any part of the work are appropriately investigated and resolved.

Ethical approval

The Institutional Review Board approved our retrospective research (Ref: 2674/QĐ-ĐHYHN dated July 13, 2021).

Availability of data and material

The datasets generated and analyzed during the present study are not publicly available due to privacy concerns but are available from the corresponding author on reasonable request.

Declaration of patient consent

The Institutional Review Board (IRB) permission obtained for the study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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