Image scoring system for umbilical and uterine artery pulsed wave Doppler ultrasound measurement

M. Molloholli,[1] R. Napolitano,[1] E.O. Ohuma,[1,2] S. Ash,[1] S.Z. Wanyonyi,[1] A. Cavallaro,[1] A. Giudicepietro,[1] F. Barros,[3,4] M. Carvalho,[5] S. Norris,[6] M. A.M. Min,[7] G. Zainab,[8] A.T. Papageorghiou.[1]

1. Nuffield Department of Women's & Reproductive Health and Oxford Maternal and Perinatal Health Institute, University of Oxford, Oxford, United Kingdom;
2. Centre for Statistics in Medicine, Botnar Research Centre, University of Oxford, Oxford, United Kingdom;
3. Programa de Pos-Graduacao em Epidemiologia, Universidade Federal de Pelotas, Pelotas, Brazil;
4. Programa de Pos-Graduacao em Saude e Comportamento, Universidade Catolica de Pelotas, Pelotas, Brazil;
5. Faculty of Health Sciences, Aga Khan University, Nairobi, Kenya;
6. Developmental Pathways for Health Research Unit, Department of Pediatrics and Child Health, University of Witwatersrand, Johannesburg, South Africa;
7. Shoklo Malaria Research Unit, Maesod, Tak, Thailand;
8. Department of Pediatrics and Child Health, Aga Khan University Hospital, Karachi, Pakistan.

Corresponding Author:
Prof. Aris Papageorghiou
St George's Hospital Medical School
Fetal Medicine Unit
Blackshaw Rd
London, SW17 0RE
Email: apapageo@sgul.ac.uk

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Abstract

Objective: To develop an objective, image scoring system for pulsed wave Doppler measurement of maternal uterine and fetal umbilical arteries, and evaluate how the system compares with subjective assessment of the images.

Methods: As part of the quality control strategy for the INTERGROWTH-21st Project, we developed a scoring system based on six predefined criteria for uterine and umbilical artery pulsed wave Doppler measurement. The scoring system was compared to subjective assessment, which consisted simply of classifying an image as acceptable or unacceptable. Based on a sample size estimate, a total of 120 ultrasound images of umbilical and uterine artery Doppler were randomly selected from the INTERGROWTH-21st database. Two independent reviewers evaluated these images in a blinded fashion both subjectively and using the six-point scoring system. The percentage agreement and kappa statistic between the two methods were compared.

Results: The overall agreement between reviewers was higher for objective assessment using the scoring system (agreement: 85%, adjusted kappa: 0.70), than for subjective assessment (agreement: 70%, adjusted kappa: 0.47). The levels of agreement for the six components of the scoring system were: anatomical site (adjusted kappa: 0.97), sweep speed (0.88), magnification (0.77), velocity scale (0.68), image clarity (0.68), and angle of insonation (0.65).

Conclusion: In quality assessment of umbilical and uterine artery pulsed wave Doppler measurements, an objective six-point image scoring system is associated with greater reproducibility than subjective assessment. We recommend this as the preferred method for quality control, audit and teaching.

INTRODUCTION

Doppler ultrasound is a safe and non-invasive way of evaluating blood flow *in vivo* (1), which plays an important role in identifying and managing pregnancies at high risk of preeclampsia, fetal growth restriction (FGR), small for gestational age (SGA), and perinatal morbidity (2). In high-risk women, especially those with hypertensive disease and suspected FGR, the use of Doppler ultrasound is associated with a reduced number of perinatal deaths and unnecessary medical interventions (3).

The International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) practice guidelines for Doppler use in pregnancy recommend considering a number of factors to optimise image quality, and improve the accuracy and reproducibility of measurements. These include taking the measurements during fetal quiescence in the absence of breathing or body movements; consideration of color flow mapping to identify the vessels of interest, and ensuring optimal angle of insonation, horizontal sweep speed, gain, and pulsed wave frequency (4). The aim of these is to improve the reproducibility and accuracy of measurements; for example, a change in the angle of insonation of only 10° corresponds to a 2% velocity error, whilst a 20° angle corresponds to a 6% error (4).

Although different techniques and some optimum criteria have been described for Doppler in pregnancy (5), we have been unable to identify any formal scoring systems or objective assessments. Such scoring systems are used (and are more reproducible than subjective assessment) in fetal biometry (6), nuchal translucency and measurement of crown rump length (CRL) (7-10). Therefore, given the need to maximise the quality of Doppler imaging in obstetric practice, we aimed to develop an objective image-scoring system for Doppler ultrasound of the fetal umbilical and maternal uterine arteries, and to evaluate how this compares with a subjective assessment.

METHODS

In an extension to the INTERGROWTH-21st Project (11), which aims to improve the phenotypic characterisation of the FGR, SGA and preterm birth syndromes (12, 13), pregnant women were recruited at 9+0 to 13+6 weeks of gestation, as determined by standardised CRL measurement (14). Their babies were then assessed during pregnancy, at birth, and at 1 and 2 years of age (11). The ultrasound protocol includes measurement of fetal biometry every 5 ± 1 weeks from recruitment until birth (15). In addition, uterine artery Doppler was measured once, between 19^{+0} and 23^{+6} weeks, and umbilical artery Doppler at every scan from 24^{+0} weeks of gestation. Doppler assessment was undertaken according to a pre-specified protocol using, at every study site, the same commercially available ultrasound machine with curvilinear abdominal transducers C5-2, C6-3, V7-3 (Philips HD-9, Philips Ultrasound, Bothell, WA, USA) (15). All Doppler images were taken by trained sonographers who underwent a specific standardisation process, similar to that for fetal biometry (16). All ultrasound images were stored at the Ultrasound Quality Control unit in Oxford (17).

For umbilical artery Doppler, the signal was obtained from a free loop of the umbilical cord during a period of fetal quiescence (absence of significant limb or breathing movements); having identified the vessel with color Doppler, 4-6 consistent waveforms were then obtained with the pulsed wave Doppler gate. For uterine artery Doppler, each artery was identified using color flow mapping at the crossover with the external iliac artery; 4-6 similar waveforms were then obtained with pulsed wave Doppler using an appropriate gate size and minimum angle of insonation.

For both umbilical and uterine Dopplers, the Pulsatility index (PI), Resistance index (RI), Systolic/Diastolic ratio (S/D) were measured after angle correction. The auto tracing was used on three or more consecutive similar waveforms, from the beginning of the systolic to the end of the diastolic signal. In case where this was not possible, a manual trace was used for these calculations. For umbilical artery Doppler, end diastolic flow (EDF) was reported as present, absent or reversed. For uterine artery Doppler, presence of an early diastolic "notch" recorded for each vessel (defined as a clearly defined upturn of the flow velocity waveform at the beginning of diastole in all waveforms)(5).

Images were selected at random from the INTERGROWTH-21st database using a randomisation algorithm. Subjective and objective assessments of all images were then performed by two independent reviewers (A and B) who were blinded to each other's results, and to the original sonographer's findings. The two assessments were undertaken 2 months apart to try to prevent the reviewers remembering individual cases.

- For subjective assessment, the reviewers were asked to rate the images as either "acceptable" or "unacceptable" based on their appearance, based on clinical practice.
- For objective assessment, a new six-point image scoring system was developed, based on recommended and established standards for Doppler measurements (4, 5, 18) (Table 1). Reviewers assigned 0 or 1 points depending on whether a criterion was met or not (Figure 1-4). All six criteria were accorded equal weight: therefore, the maximum score for an image was 6. For comparison with the subjective assessment, scores of 4-6 were classified as "acceptable", and those 3 or less "unacceptable" (Figure 5).

Statistical analysis

Based on findings from previous studies (6, 10), we estimated that a total of 120 images would be needed to detect a 10% difference (inter-observer agreement) between two reviewers with 90% power, assuming an inter-observer agreement rate of 80%. To establish which assessment method has greater reproducibility, prevalence-adjusted, bias-adjusted kappa coefficients were used to determine the inter-observer agreement for the two methods.

RESULTS

Both reviewers undertook subjective and objective assessments of 120 umbilical and uterine artery pulsed wave Doppler images.

For the subjective assessment, 47/120 (39.2%) images were classified as unacceptable by reviewer A, 23 (19.2%) by reviewer B, and 19 (15.8%) by both reviewers. This resulted in an overall inter-observer agreement of 70% [adjusted kappa, 0.47 (95% CI, 0.31-0.62)]. The inter-observer agreement for the objective assessment was higher: 85% [adjusted kappa, 0.70 (95% CI, 0.58 – 0.83)].

Ten images with an objective score of 5 or 6 were classified subjectively as unacceptable by reviewer A *or* B. None of the images classified as subjectively unacceptable by *both* reviewers scored 6, and only one scored 5, in the objective assessment (Table 2). Conversely, 22 images classified subjectively as acceptable had a low (≤3) objective score, demonstrating the higher agreement of objective assessment.

The degree of agreement between the two reviewers for the individual scoring criteria was also examined: agreement was highest for the anatomical site (98.3%) and sweep speed (94.2%), and lowest for the angle of insonation (82.5%) (Table 3).

DISCUSSION

Quality assessment of Doppler images can be undertaken subjectively, simply by judging an image to be acceptable or not based on its appearance, or more objectively using criteria specifically derived for that purpose. In this study, we have shown that the six-point scoring system we have developed to assess Doppler images objectively is more reproducible than subjective assessment. This is an important finding as improvements in quality assessment should not only help the clinical management of individual pregnancies but also help to identify sonographers who might benefit from further training and focussed feedback.

We believe that all ultrasound units should be striving to improve the overall quality of Doppler image interpretation and measurement. Poor technique may make normal blood flow appear sub-optimal: for example, a poor angle of insonation and incorrect scale may make end-diastolic frequencies “disappear” within filter settings in umbilical artery Doppler waveforms, creating false positives. Conversely, false negatives may arise from insonating low resistance spiral, instead of uterine, arteries (19).

Quality control plays a significant role in reducing the number of false positives in screening programmes: for example, in nuchal translucency screening, the absence of quality control impacts markedly on clinical practice (7). Similarly, a lack of standardisation and quality control when measuring fetal biometry in ultrasound studies risks methodological bias and can lead to heterogeneous results (5, 20). For the uterine artery Dopplers, criteria used by the Fetal Medicine Foundation (FMF) for audit of first trimester preeclampsia screening (21) also informed our study; some of the criteria were adjusted (as we measured uterine Dopplers later in gestation) and extended.

Objective assessment is associated with a higher level of agreement than subjective assessment, and it ensures that individual parameters are evaluated. Assessment of anatomical site, sweep speed and magnification were associated with a high level of agreement (adjusted kappa > 0.7); the agreement for the assessment of the angle of insonation, image clarity and velocity scale (adjusted kappa: 0.65, 0.68, 0.68, respectively) was almost as good, and much better than for subjective assessment (adjusted kappa: 0.47). This is in keeping with previous studies that found objective assessment to be more reproducible than subjective assessment in second trimester fetal biometry, nuchal translucency, nasal bone and CRL measurement (6, 8, 9, 19, 23-24); it also links to efforts by organisations such as the Fetal Medicine Foundation (FMF) and ISUOG in creating guidelines and audit tools. In the case of fetal biometry, such quality control and standardisation processes led to measurable improvements in inter-observer variability in the INTERGROWTH-21st Project (16).

Our study had a number of strengths. Firstly, trained and standardised sonographers collected the ultrasound data prospectively using the same ultrasound machine at each study site. Secondly, we undertook a sample size estimate prior to sampling randomly from the large INTERGROWTH-21st image database, and the reviewers were blinded to each other's assessments and to the sonographers' original findings. Lastly, as most images were of high quality, prevalence adjusted kappa was used to minimise bias (25).

The study also had some limitations. In the objective assessment, all criteria had the same weight in the final score even though some parameters are probably more important than others in ensuring a good Doppler signal. Having said that, a complicated scale that weights criteria differently would be methodologically complex as the elements are related to each other; and difficult to use in routine clinical practice. A similar approach has proven effective in obtaining optimal reproducibility in a large scale quality control study on fetal biometry (17). Another possible limitation is that, in the time between the color flow image being frozen and freezing of the final pulsed Doppler signal, movements might have occurred that could have changed the angle of insonation at the time of acquisition; however, this is unlikely to be significantly different to the angle seen on the frozen color flow image.

We also appreciate that we set a rather arbitrary cut-off for dividing the images into acceptable and unacceptable classes based upon the scores in the objective assessment; however, the use of such a cut-off is in keeping with recommendations in the literature and the aim to derive a practical system based on accepted guidelines.

CONCLUSION

Previous studies have demonstrated the value of umbilical artery Doppler in the management of high-risk pregnancies and of risk identification using uterine artery Doppler screening. Both methods require accurate measurement of pulsed-waved Doppler. We demonstrate that objective assessment using a six-point scoring system is more reproducible than subjective assessment and should be the preferred method for quality control, teaching and auditing in research studies and clinical practice.

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Figure Legends

Figure 1. Color and pulsed wave image showing the correct way of measuring umbilical artery Doppler. High motion filter and baseline were reduced to a minimum to increase the magnification of the velocity scale. Note that there is no venous or arterial reversed pulsed waved Doppler signal evident below the baseline.

Figure 2. Color and pulsed wave image with correct measurement of uterine artery Doppler. Note that the angle of insonation has been corrected. High motion filter and baseline were reduced to a minimum to increase the magnification of the velocity scale. Note that there is no venous or arterial reversed pulsed waved Doppler signal evident below the baseline.

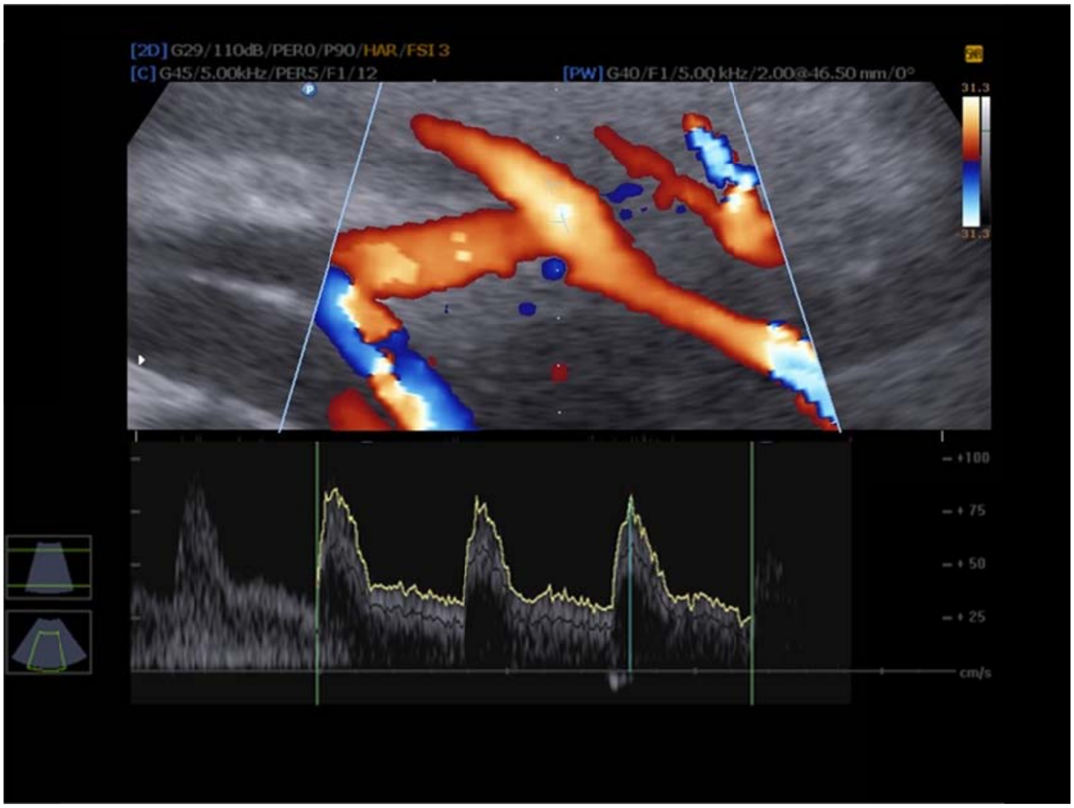

Figure 3. Assessment of umbilical artery Doppler demonstrating poor magnification of the anatomical site of the sample; velocity scale less than 75% and sweep speed more than 4-6 waveforms.

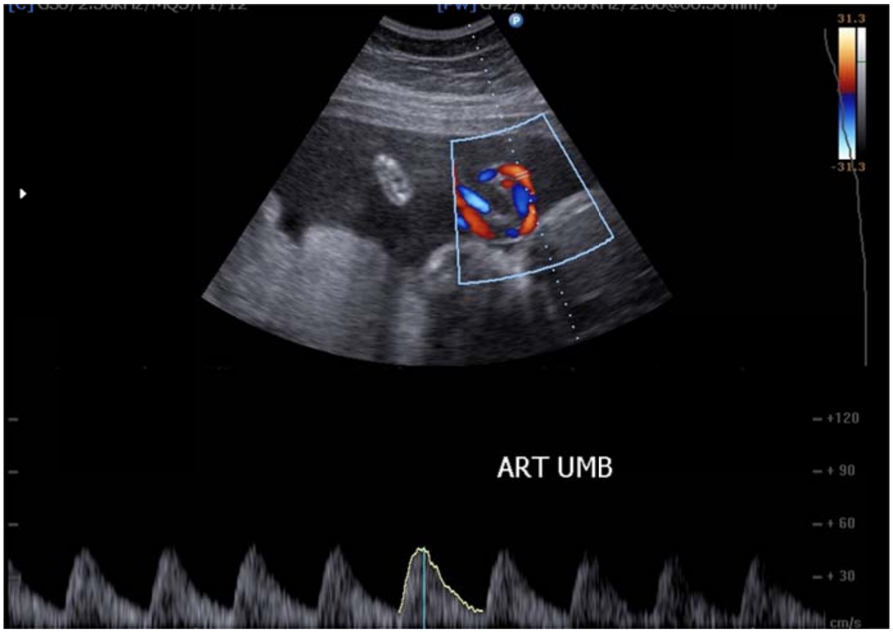

Figure 4. Assessment of uterine artery Doppler demonstrating poor magnification of the anatomical site of the sample and an angle of insonation greater than 30 degrees.

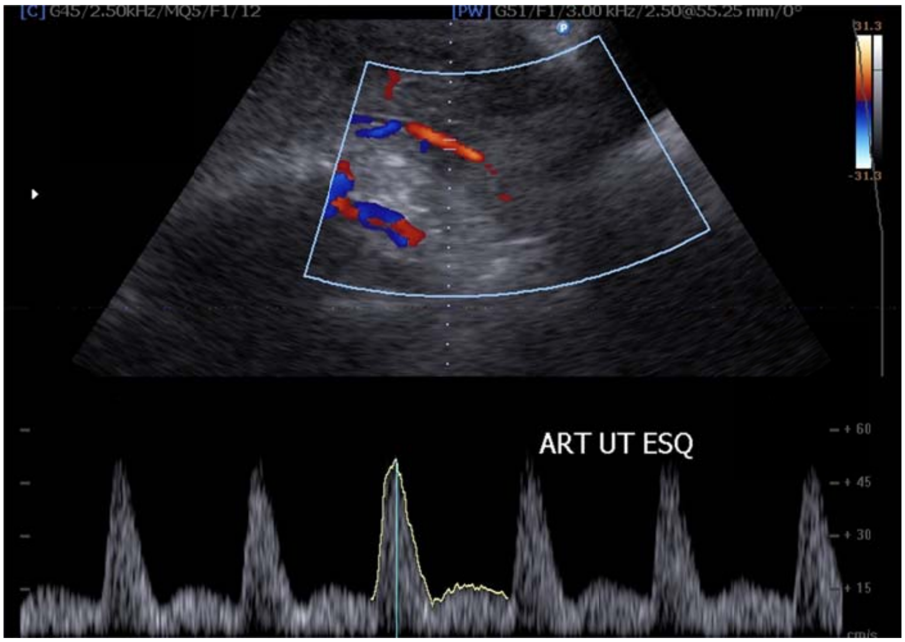

Figure 5. Frequency distribution of objective assessment for the two reviewers.

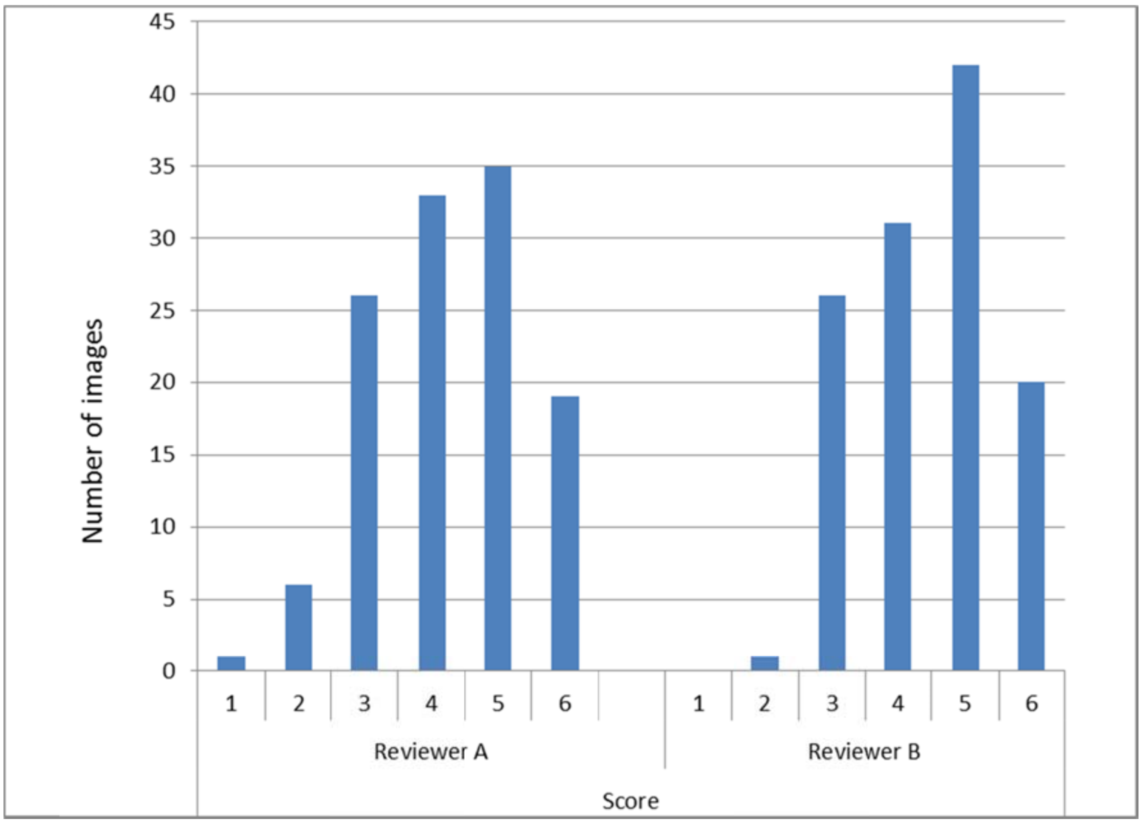

Table 1. Image six-point scoring criteria for umbilical and uterine artery Doppler measurement

Criteria	Description
1. Magnification	50% of the screen with zoom box and sample gate in the centre of the vessel
2. Angle of insonation	Less than 30^o
3. Sweep speed	4-6 waveforms with consistent and similar signal
4. Clarity of the image	Pulse rate frequency and color gain correction (avoid venous signal)
5. Anatomical site of the sample	Umbilical artery: free loop. Uterine artery: before the bifurcation above the iliac vessels
6. Velocity scale	75% of the peak systolic velocity

Table 2. Distribution of objective image score for each subjective image rating for pulsed wave Doppler measurement for reviewers A and B

Subjective Assessment	**Objective Assessment Score**					
	1	2	3	4	5	6
Unacceptable (A)	1 (0.8)	5 (4.2)	16 (13.3)	16 (13.3)	6 (5)	3 (2.5)
Acceptable (A)	-	1 (0.8)	10 (8.4)	17 (14.2)	29 (24.2)	16 (13.3)
Unacceptable (B)	-	1 (0.8)	15 (12.5)	6 (5)	1 (0.8)	-
Acceptable (B)	-	-	11 (9.2)	25 (20.8)	41 (34.2)	20 (16.7)
Unacceptable (A and B) & Objective Assessment (A)	1 (5.3)	5 (26.3)	9 (47.4)	4 (21.1)	-	-
Unacceptable (A and B) & Objective Assessment (B)	-	1 (5.3)	11 (57.9)	6 (31.6)	1 (5.3)	-
Acceptable (A and B) & Objective Assessment (A)	-	-	7 (10.1)	16 (23.2)	29 (42)	17 (24.6)
Acceptable (A and B) & Objective Assessment (B)	-	-	7 (10.1)	14 (20.3)	32 (46.4)	16 (23.2)

Data given n (%); A: reviewer A; B: reviewer B.

Table 3. Adjusted kappa and percentage of agreement for individual criteria of pulsed wave Doppler objective assessment

Criterion	Adjusted kappa (95% CI)	Agreement (%)
Magnification	0.77 (0.65-0.88)	88.3%
Angle of insonation	0.65 (0.52-0.78)	82.5%
Sweep speed	0.88 (0.80-0.97)	94.2%
Image clarity	0.68 (0.56-0.81)	84.2%
Anatomical site	0.97 (0.92-1.01)	98.3%
Velocity scale	0.68 (0.55-0.81)	84.2%

CI: confidence intervals