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Increasing the Detection Rate of Normal Foetal Cardiac Structures: A Real-Time Approach

Abstract

The purpose of this study was to determine if acquiring real-time sweeps of the foetal heart would be a more effective method of identifying normal cardiac structures compared with using static images during routine 2^{nd} trimester obstetric sonograms. Subjects were scanned using three different techniques. The static image acquisition, protocol A, included three images of the foetal heart. Protocol B used two grey scale sweeps through the foetal heart. Protocol C acquired three colour loops of the foetal heart. The grey-scale sweeps demonstrated a complete normal cardiac assessment in 71% of studies compared with the static image and colour Doppler techniques that completed a normal cardiac assessment in only 39% of studies, respectively. The real-time technique detected four chambers, LVOT, RVOT, the LVOT/RVOT cross over, size and axis of the heart with a greater frequency than the static images and colour loops in all cases. In addition the real-time technique was able to demonstrate the pulmonary veins in 56% of cases compared with 3.6% for static images. The colour Doppler acquisition demonstrated blood flow through the atrial-ventricular and semi-lunar valves in 86% of cases.

Key words: sonography, foetal heart, real-time, static, detection, tissue harmonic

Introduction

The use of ultrasound imaging for routine fetal screening in the second trimester has been adopted by the Canadian health care system and a number of European countries as a standard of care[1]. According to a survey of 2758 referrals to the fetal cardiology unit at Guy's Hospital, London, UK, the low risk population for congenital heart defects is the source of 80% of congenital heart defects.[2] This fact underscores the importance of routine screening for detection of congenital heart defects. Routine screening provides a more accurate measure of gestational age, earlier detection of multiple pregnancies and may detect congenital malformations. The Eurofetus study identified marked differences in sensitivity for detection of different malformations. Abnormalities of the urinary system and nervous system were most easily detected with a sensitivity of 88.5% and 88.3% respectively.[1] In this study cardiac abnormalities were not well detected, sensitivity for major cardiac defects was 38.8% and minor defects 20.8%.[1] In Canada, an obstetric screening examination is performed in real-time and documented as a series of still images archived electronically or on film. The interpretation of the cardiac images is performed by a radiologist or obstetrician using the still images. Present detection rates for congenital heart defects (CHD) vary widely depending on a number of factors, operator skills, maternal obesity, fetal position, inadequate image optimization, and visualization of the four chamber view only.[3] The American College of Radiology (ACR) and the International Society of Ultrasound in Obstetrics & Gynecology (ISUOG) have published guidelines for routine second trimester screening that require the four chamber view and where possible, views of the left ventricular outflow tract (LVOT) and right ventricular outflow tract (RVOT) to address this limitation.[4,5]

Acquisition of static images of the fetal heart provides a very limited quantity of diagnostic information, the identification of normal cardiac structures cannot be completely demonstrated as a series of a few static slice images. The interpretation of key structural relationships can only be completed during a real-time interrogation. In practice the detection of the critical normal structures is accomplished solely by the sonographer. This approach limits the interpreter's ability to confirm the findings of the sonographer. The main objective of this pilot study is to demonstrate that acquiring real-time loops of the foetal heart can be accomplished with minimal additional acquisition time and skill. In addition the static and real-time techniques will be compared in an effort to demonstrate the additional anatomical information that is accessible using a real-time acquisition. The real-time loops will add considerable diagnostic value to the screening process since there will be two interpretations performed on every exam, the preliminary review by the sonographer and the summary review by the sonologist. In addition using the real-time loops will provide the sonologist the opportunity to review the images repeatedly in real-time and evaluate structures at different points during the cardiac cycle. The ability to assess structures during the diastolic phase has been found by Chaoui (2003) to be helpful in detecting atrioventricular septal defects.[6] Further, it is well established that observation of moving structures provides a more sensitive means of detecting small differences in form.[7] A cine loop of a sweep through the cardiac outflow tracts will allow the sonologist to better appreciate the relationship between the LVOT and RVOT which is crucial for ruling out conotruncal abnormalities. Hosono et al, (2002) found the use of tissue harmonic imaging to be advantageous in imaging fetal cardiac tumours due to improvements in image contrast.[8] Using THI will improve the quality of the images and may influence the detection rate of cardiac structures as well.

Acquisition of real-time loops assumes the ultrasound systems that are used are capable of storing and transmitting real-time loops to a network. A survey of 21 local screening centers illustrated in table 1 found that 95% of centers were acquiring and storing images electronically using a Picture Archiving Communications System (PACS). The majority of centers acquired three static images of the foetal heart, the four chamber view, the LVOT and RVOT view (see table 1). For the purpose of this pilot this combination of static images represents the conventional technique, protocol A.

RESEARCH QUESTION/OBJECTIVES

Comparison of static and real-time imaging techniques applied to the assessment of the fetal heart in routine screening.

Research Aims

- Demonstrate the ability to acquire the experimental protocol B in less than five minutes
- Demonstrate an increased rate of detection of cardiac structures using real-time compared with static images

METHODOLOGY

The research protocol was reviewed and approved for use by the ethics committee of Charles Sturt University (Wagga Wagga, NSW, Australia) and the ethics committee of Mohawk College (Hamilton, Ontario, Canada). Exclusion criteria included a family history of congenital heart defects or an abnormal 2^{nd} trimester obstetric sonogram. All 28 subjects had a normal 2^{nd} trimester sonogram prior to participation in this study. Images were acquired using Philips Medical Systems, HDI 5000 and Envisor sonography systems. Images were acquired using a curvi-linear array transducer with a fetal cardiac preset using tissue harmonic image processing.

Subjects were scanned using three different techniques. The static image acquisition, protocol A, acquired 3 images of the foetal heart, the four chamber view, the left ventricular outflow tract (LVOT) view and right ventricular outflow tract (RVOT) view (see figures 1-3). The real-time sweep, protocol B acquired two grey scale sweeps of 4 four seconds duration each through the foetal heart. The first sweep began at the level of the transverse abdominal circumference with a visible stomach and swept into the transverse four chamber view. The second sweep began at the four chamber view and swept through the LVOT and RVOT (see figures 4-7). Using protocol C, three real-time colour cine-loops of four seconds duration were acquired. The first was a sweep from the level of the transverse abdominal circumference with a visible stomach into the transverse four chamber view. The second sweep began at the four chamber view and swept through the LVOT and RVOT. The third was a colour cine-loop of the three vessel view.

Informed consent was obtained and then subjects were randomly assigned a sonographer who completed either protocol A, B or C. A total of five sonographers acquired images for this project. All sonographers had a minimum of 3 years experience in obstetrical sonography and were ARDMS credentialed as RDMS (obstetrics and gynecology). The sonographer recorded the scan time for the acquisition using an electronic timer. Every subject was scanned by at least two different sonographers. Images were acquired and stored on the Philips Medical Systems Xcelera Minipacs. No additional training was provided to save the real-time loops compared with the static images. Sonographers were limited to a maximum of 10 minutes to complete each protocol in an effort to replicate the practical limitations of the clinical environment.

The image sequences acquired were reviewed independently by two different fetal cardiac sonography experts blinded to each others' results. The reviewers are expert in acquiring and interpreting fetal cardiac sonograms. The first was a sonographer (jj) with 16 years pediatric cardiac experience registered with RDCS (pediatric and fetal echo) credentials and the second a Pediatric Cardiologist (tm). In addition to the expert reviewers, two non-experts reviewed the images independently and were blinded to each others results. The first was a radiology resident in year three of his training (KG) and the second was a cardiac sonographer with RDCS credentials and less than one year of experience in performing fetal cardiac studies. Each observer recorded the detection of five cardiac structures listed in table 3 as, detected = 1 or, missed = 0. A complete normal assessment requires a score of 5, an incomplete assessment is recorded as any total less than 5.

Statistical Analysis

Inter-observer differences were tested using a Kappa score for agreement between detection of structures. A one way ANOVA was performed to test for agreement between the means of total detection rate scores and the means of the acquisition times. Detection rate differences for complete and incomplete assessments were analyzed using the McNemar Chi-square test.

Results

The subjects' average gestational age was 27 weeks 0 days, with an average BMI = 27.8 and an average body wall thickness = 1.8 cm (see Table 2). The acquisition time for the static images, protocol A is statistically equivalent to the acquisition time for protocol B and the mean time for both is less than 5 minutes (see Table 2). The acquisition of protocol C exceeded 5 minutes with a mean time of 6:32, statistically different than protocols A and B. Inter- observer agreement for detection of cardiac structures using static images ranged from fair to excellent using Kappa scores. Inter-observer agreement for detection of cardiac structures using real-time images ranged from excellent to poor using Kappa scores. Should these inter-observer Kappa statistics also be included in a separate table?

Detection Rates

The real-time image loops were found to have the highest detection rates for all anatomic structures compared with the static images and color loops (see table 3.) The four chamber view was identified in 100% of all real-time loops and in only 68% of static images, and 84% of color loops. The LVOT and RVOT cross-over was detected in 73% of real-time loops and only 47% of static images. Similar differences were found for the LVOT and RVOT as individual structures. Using the static images, 39% of studies generated a score of 5 for complete assessment compared with the real-time technique that was able to completely assess the normal structures in 71% of studies. This generated a statistically significant difference between proportions = 0.321, p= 0.0352 using the McNemar Chi-square test.

The color Doppler loops provided a complete assessment in only 39% of cases. The color Doppler loops did provide the ability to assess the blood flow through the atrial-ventricular valves and semi-lunar valves in the majority of cases and this represents additional diagnostic information compared with the grey-scale static and real-time loops. The color Doppler loops were able to assess the four chamber view and five chamber view in the majority of cases. The 3 vessel view was only achieved in 45% of cases (see table 4).

Expert/Non-expert Differences

The expert reviewers and non-expert reviewers were found to agree closely in their assessment of static images. The largest difference between these groups was in evaluation of the LVOT with a difference of 13% between groups (see table 5.) All other structures differed by less than 10% respectively. There was close agreement between the experts and non-experts interpreting the grey scale and color loops with the exception of the four chamber view where the grey scale loop differed by 14% and the color loop differed by 11%. Assessment of a complete exam was in close agreement between experts and non-experts for the static images with a greater difference of 15% and 28% demonstrated in table 5, with the grey scale and color loops respectively.

Sample Images

The static image of the four chamber view allows the observer to distinguish the axis, size and left/right chambers under ideal conditions (see Fig. 1.) The static images of the LVOT and RVOT, (see figures 2 and 3) will describe continuity between the outflow tracts and the corresponding chambers under ideal conditions. The static images cannot effectively assess the cardiac valves or cardiac motion.

Static images have been extracted from the real-time loops in an attempt to demonstrate the added value loops provide. The first sweep begins at the transverse abdominal circumference (see Fig. 4). The four chamber view is visualized next in figure 5. The second sweep demonstrates the LVOT in figure 6 and the RVOT is visualized in figure 7. In addition the real-time sweeps provided continuity between the stomach and abdominal circumference in 100% of real-time studies. One or more pulmonary veins were visualized as contiguous structures with the left atrium in 56% of real-time cases compared with 3.6% of cases with static images (see Fig. 8). A color image extracted from a sweep from the abdominal circumference to the four chamber view demonstrated blood flow through the atrial-ventricular valves in figure 9. The blood flow through the LVOT is evident (see figure 10.) as an image acquired during the sweep from the four chamber through the outflow tracts. In figure 11 the great vessels demonstrate antegrade blood flow in a three vessel view.

Discussion

The subjects were a representative sample of expectant mothers in the late second trimester and early third trimester. The requirement of a normal diagnostic second trimester sonogram result as a prerequisite for participation in this study resulted in the mean gestational age of 27 weeks 0 days. The real-time sweeps were acquired as quickly as the static images and very little additional expertise was required to capture the real-time loops.

The structure of the heart is complex and relationships and continuity between structures such as the cross over of the outflow tracts are critical for determining normalcy. Three static views of the four chamber and outflow tracts are inadequate for complete assessment in the majority of cases. Static images are much less likely to be able to demonstrate subtle anatomic structures such as the moderator band, atrio-ventricular valve offset, that are useful for distinguishing the left and right chambers. Static images cannot assess the valves and their motion effectively and this limits observer confidence in detecting the outflow tracts and their relationship. The real-time loops are able to detect these subtle anatomic structures and their motion, this fact is reflected in the ability of the real-time loops to detect a complete normal heart in 71% of studies compared with 39% of static studies. In addition to the identification of the four chamber and outflow tracts, the real-time sweeps provided the continuity of the left sided stomach in the abdomen as the sweep translates from the abdomen to the chest in 100% of cases.

In a few cases the relationship between the outflow tracts could not be established in static images or real-time at normal speed, however using a frame by frame analysis we were able to establish that relationship. This affirms the value of acquiring loops of information rather than individual slices as well as the need to reevaluate the heart in real-time after the image acquisition process.

The color Doppler loops provided useful blood flow information in most cases but this advantage was limited to some degree by the fact that color blooming had the effect of obscuring part of the anatomy represented in grey-scale. Unfortunately our PACS and ultrasound systems did not permit the suppression of color. Another drawback to the color Doppler was the need for additional operator expertise to fine tune the color velocity scale or pulse repetition frequency (PRF) and color gain. The three vessel view was detected in only 45% of cases compared with 91% and 84% for the four chamber and five chamber views. This difference most likely reflects the relative difficulty in acquiring the 3 vessel view compared with the four chamber and five chamber views.

It is interesting to note that in nearly all cases there were only minor differences in the detection rates between the expert image reviewers and non-expert reviewers. Review of the static images resulted in the least difference between these groups, likely due to the fact that reviewers assessed only one image/view in comparison with the real-time loops that generated a series of 120 images from a 4 second acquisition. The cine-loops provided the reviewers with so much additional information it had the effect of introducing a wider range of interpretation. Based on these findings, it is clear that the identification of the four chambers, outflow tracts, outflow tract cross over, situs and location can be achieved consistently by experts and non-experts.

Real-Time Methodology

Typically 2nd trimester screening exams are scheduled for approximately 30 minutes in which time the sonographer is obliged to interrogate the maternal pelvic and foetal anatomy, as well as acquire representative images and measurements to estimate gestational age. Foetal cardiac anatomy owing to its complex shape and rapid movement represents the sonographer’s greatest diagnostic challenge compared with static foetal anatomical structures such as the brain or abdominal organs. Given these constraints, a robust screening technique needs to be able to provide the maximum relevant anatomical information with the minimum operator skill and time. For most screening centers a reasonable goal would be to identify an abnormal heart and refer the patient to a pediatric cardiology laboratory to diagnose the specific nature of the defect. The use of color Doppler cine-loops did provide additional blood flow information in the majority of cases but this advantage was off set by the additional time required to acquire these loops, the additional operator skill that is needed to apply color Doppler effectively and the fact that the color may obscure visualization of some grey scale anatomy unless it is suppressed. For these reasons it is proposed that the two sweep cine-loop acquisition technique tested in this study be used for assessing the foetal heart in the second trimester. Applying this method of acquisition will allow the image interpreter to identify the key cardiac anatomical landmarks and relationships that were assessed in this study in the majority of cases. This method will provide the most effective assessment of foetal cardiac anatomy with a minimum of additional time or skill.

Study Limitations

It was not possible to blind the observer to the techniques used for acquisition since a static image is inherently different to a real-time loop. The manipulation of the real-time loops as a frame by frame analysis was left to the discretion of the individual reviewers. While this may have limited the standardization of the image presentation the manipulation of frame rate by the user is a key advantage of the technique.

Conclusion

Real-time sweeps through the fetal heart are easily and rapidly acquired with minimal additional operator skill. Acquiring four- second, real-time loops provides the sonologist with the information required to more effectively assess the fetal heart. Real-time sweep acquisitions of fetal cardiac structures are much more effective in completing a normal assessment. This study was able to demonstrate a complete cardiac assessment in 71% of studies using a real-time acquisition technique compared with 39% of static image acquisitions. The use of color Doppler provided blood flow information of the atrial-ventricular valves in 86% of subjects. A standardized two sweep acquisition through the fetal heart can be acquired quickly and with minimal additional operator skill. In the future, studies comparing the performance of this technique between normal and abnormal fetal hearts will be needed to demonstrate the clinical value of real-time loops for detecting congenital heart disease.

Reference:

1. Johnson, J, 'Overview of Obstetric Sonography", 2005, in *Diagnostic Ultrasound*, Rumack, C, Wilson, S, Charboneau, (3rd ed.), Elsevier Mosby, St.Louis Missouri, USA

2. Sharland, G 2004, 'Routine fetal cardiac screening: what are we doing and what should we do?', *Prenat Diagn*, vol. 24, pp.1123-1129.

3. Wong, S, Chan, F, Cincotta, R, Lee-Tannock, A, Ward, C, 2003, 'Factors influencing the prenatal detection of structural heart diseases', *Ultrasound Obstet Gynecol*, vol 21, pp. 19-25.

4. ACR, 2003, 'ACR practice guideline for the performance of antepartum obstetrical ultrasound', *Antepartum Obstetrical Ultrasound*, pp. 781-787.

5 ISUOG Education Committee, (Year??) 'Cardiac screening of the fetus: guidelines for performing the 'basic' and 'extended basic' cardiac scan', *Ultrasound Obstet Gyneco*l, vol. 27, pp. 107-113

6. Chaoui, R 2003, 'The four chamber view: four reasons why it seems to fail in screening for cardiac abnormalities and suggestions to improve detection rate', *Ultrasound Obstet Gynecol*, vol. 22, pp.3-10

7. Ivry, R, Cohen, A, 1992, 'Asymmetry in Visual Search for Targets Defined by Differences in Movement Speed', *Journal of Experimental Psychology Human Perception and Performance*, vol.18. No.4, pp. 1045-1057.

8. Hosono, T, Chiba, Y, Kanai, H, Kanagawa, T, 2002, 'Initial experiences of tissue harmonic imaging in the diagnosis of fetal cardiac tumors', *Ultrasound Obstet Gynecol*, vol. 19, pp. 400-402.