Three-Dimensional Fast Acquisition With Sonographically Based Volume Computer-Aided Analysis for Imaging of the Fetal Heart at 18 to 22 Weeks’ Gestation

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Objective. The purpose of this study was to determine how frequently cardiac images derived from 3-dimensional (3D) volume sets, acquired by fast acquisition and evaluated with sonographically based volume computer-aided analysis (sonoVCAD), were satisfactory for prenatal screening at 18 to 22 weeks’ gestation. Methods. A prospective study of 100 women with singleton pregnancies was undertaken. Three fast acquisition 3D volume sets were obtained from each patient. Four reviewers independently evaluated the 4-chamber and 5 extracted VCAD views. Factors contributing to unsatisfactory screening were also evaluated. Results. The frequency with which adequate views for cardiac screening could be obtained varied widely; some single views, such as that of the stomach, were well seen frequently, whereas others, such as the ductal arch, were well seen significantly less frequently (P < .05). A satisfactory screening examination, defined as a visualized 4-chamber, left ventricular outflow tract, right ventricular outflow tract, and axial stomach view, was obtained for 43% to 65% of patients (dependent on reviewer). Logistic regression revealed that obesity (odds ratio, 3.0; 95% confidence interval, 1.7–5.0) and a fetus with the spine toward the maternal abdomen (odds ratio, 1.7; 95% confidence interval, 1.1–2.5) were independently associated with an unsatisfactory screening examination. Conclusions. Three-dimensional fast acquisition volumes evaluated with sonoVCAD did not allow a satisfactory fetal cardiac screening examination to be obtained a high percentage of the time in a general obstetric population during the second trimester. Certain patient factors, such as body habitus and fetal position, are associated with unsatisfactory 3D imaging. Key words: computer-aided analysis; fetal heart; 3-dimensional screening.

Abbreviations
BMI, body mass index; LVOT, left ventricular outflow tract; RVOT, right ventricular outflow tract; sonoVCAD, sonographically based volume computer-aided analysis; STIC, spatiotemporal image correlation; SVC-IVC, superior and inferior vena cava; 3D, 3-dimensional; 2D, 2-dimensional

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The prenatal diagnosis of major congenital heart defects remains a challenge. Recent publications by Acherman et al1 and Sklansky et al2 have found that approximately 35% of cardiac anomalies are detected prenatally, a frequency that is not substantially different from that documented by Wigton et al3 in 1993. In an effort to improve antenatal detection of these anomalies, the American Institute of Ultrasound in Medicine, the American College of Obstetricians and Gynecologists, and the International Society of Ultrasound in Obstetrics and Gynecology, and the International Society of Ultrasound in Obstetrics and Gynecology have suggested that ultrasound examinations should attempt to include views of the cardiac outflow tracts.1–6 Other proposals have included obtaining routine 2-dimensional (2D) cine clips, universal fetal echocardiography, and routine use of 3-dimensional (3D) fast acquisition volumes.
One reason that 3D sonographic technologies have been suggested is because routine visualization of cardiac views has proven to be a challenge with 2D imaging in centers that are less experienced with prenatal diagnosis, and 3D stored volumes could then be evaluated further by those more experienced. The technique of 3D fast acquisition was described by Nelson et al in 1996. The ability of this technique to quickly capture the volume of an anatomic structure is important in cardiac imaging given the motion of the beating heart. Additionally, the technique of sonographically based volume computer-aided analysis (sonoVCAD), which semi-automatically extracts the left ventricular outflow tract (LVOT) and right ventricular outflow tract (RVOT) views from a 3D volume set, has been evaluated and described by Abuhamad et al. Their work carefully documented the spatial relationships of the standard fetal cardiac planes and suggested that sonoVCAD could be used to obtain the outflow tract views in more than 90% of fetuses at 18 to 23 weeks’ gestation. In contrast, a recent report by Uittenbogaard et al that documented 140 consecutive patients in this same gestational age range found that only 49% of the examinations could provide satisfactory images of views (4-chamber, outflow tracts, and stomach) that are necessary for screening.

The reasons for these disparate results remain uncertain, as do the factors that may influence the ability to obtain satisfactory images. This study was undertaken to evaluate the frequency with which 3D fast acquisition with sonoVCAD technology could provide images that would be satisfactory for cardiac screening as determined by experienced sonologists and to discern which factors might influence this frequency.

Materials and Methods

This study was approved by the Institutional Review Board of Northwestern University Medical School. Women with singleton gestations who were undergoing routine 2D anatomic surveys between 18 and 22 weeks’ gestation at the ultrasound laboratory of the Northwestern Medical Faculty Foundation were approached regarding enrollment in this study. Three-dimensional imaging for the study was performed only for those who signed informed consent. Women were excluded from participation if they had a body mass index (BMI) of greater than 35 kg/m² or if their fetus had a known chromosomal or anatomic anomaly.

Three 3D volumes were obtained on each patient at the level of the 4-chamber heart. Three-dimensional sweeps were performed with a 4- to 8-MHz mechanized abdominal probe (Voluson E-8; GE Healthcare, Kretztechnik, Zipf, Austria), and volume sets were manipulated with GE 4D View software (version 7). Three-dimensional fast acquisition presets were used with the input of fetal cardiac imaging specialists from GE Healthcare. The sweep speed was set at high-2, CrossXBeam Imaging at 1, harmonics at low, dynamic contrast at 8, and acquisition angle at 35°. If possible, the volumes were obtained with the fetal chest anterior or anterior oblique. All scans were performed by a single research sonographer (K.M.) with extensive experience in prenatal sonography and 3D techniques. The examination time was limited to 45 minutes with an additional 15 minutes allowed for breaks.

The technique that was used to obtain cardiac views was that initially described by Abuhamad et al. and recently reiterated by Uittenbogaard et al. The 4 chambers are rotated to the left side of the image with the spine in the 6 o’clock position. The magnification is adjusted so that the sonoVCAD form fits properly. The reference point is placed at the insertion of the tricuspid valve into the crux of the heart. The different cardiac views are automatically obtained in 5 steps: cardiac I, LVOT; cardiac II, RVOT; cardiac 3, stomach; cardiac 4, superior and inferior vena cava (SVC-IVC); and cardiac 5, ductal arch. Minor scrolling or rotation of the slice plane was allowed to improve image quality.

After the 3 cardiac volumes were obtained, a sonologist/sonographer team (L.C. and K.M.) selected the highest quality volume, which was determined by the least motion artifacts and review with the VCAD software. This volume was then sent for further review by 3 experienced obstetric sonologists (L.D.P., S.J., and J.D.) and 1 pediatric cardiologist (N.G.). These reviewers graded the 6 images on a scale of 1 to 5. The grades were 1, ideal; 2, well visualized; 3, suboptimal but satisfactory for screening; 4, poorly
visualized; and 5, visualization not possible. Any image that was awarded a grade of 1, 2, or 3 was considered to be satisfactory for screening, and this dichotomous grade was the primary outcome used for analyses. The entire examination was considered satisfactory only when the images of the 4-chamber view, LVOT, RVOT, and stomach all had been deemed satisfactory for screening. The BMI was calculated from weight and height provided by the patient at the time of the sonographic procedure.

Descriptive statistics, including the frequency of satisfactory screening views and the frequency of concordance between reviewers with regard to whether a view was satisfactory, was determined. Categorical variables were analyzed using χ² analysis. Last, the factors that were associated with a given view being considered unsatisfactory for screening were evaluated. For the purposes of this analysis, an image was considered unsatisfactory if at least 2 of the 4 reviewers designated the image as “unsatisfactory for screening”. The associations of obesity (BMI >30 kg/m²), anterior placental position, and anterior fetal spine position were assessed in relation to whether an image was unsatisfactory. Those factors that in univariable analysis had P < .10 were retained for further analysis in a multivariable logistic regression. Odds ratios and 95% confidence intervals were determined. All tests were 2 tailed, and P < .05 was used to define significance. Minitab 14 (Minitab Inc, State College, PA) was used for analysis.

Results

One hundred women consented to participate in the study. Their mean BMI ± SD was 25.1 ± 3.9 kg/m². Thirty percent of the women had a fetus in the spine-up position, and 45% had an anterior placenta. The numbers of fetuses by gestational age were 5 at 18 weeks, 28 at 19 weeks, 49 at 20 weeks, 16 at 21 weeks, and 2 at 22 weeks. Table 1 shows the frequency with which each of the 6 views was considered satisfactory for screening, stratified by reviewer. As can be seen, there was a significant difference in the frequency with which each reviewer graded individual views as satisfactory (P < .05 for each reviewer). Most reviewers, for example, found the 4-chamber and stomach views to be satisfactory most often and deemed the view of the ductal arch as satisfactory least often. The probability of an entire screening examination being considered satisfactory (ie, when the 4 designated views were all normal) was relatively low for all reviewers: 62%, 43%, 65%, and 49%, respectively.

Table 2 shows the frequency of concordance between reviewers, stratified by the type of cardiac view. Overall, concordance between reviewers was relatively high. In most instances, reviewers agreed more than two-thirds of the time with regard to whether a given view was satisfactory for screening. Concordance frequencies tended to be higher for the 4 views that commonly contribute to the standard examination and lower for the SVC-IVC and ductal arch views.

Last, factors that were associated with an image that was not satisfactory were determined. Table 3 shows the results of univariable analysis. Women who were obese as well as those with a fetus in the spine-up position were more likely to have cardiac views that were not satisfactory for screening. In logistic regression, these 2 factors, but not an anterior placental position, continued to be significantly associated with an unsatisfactory image (Table 4).

### Table 1. Frequency With Which Cardiac Screening Images Were Satisfactory for Screening Stratified by Reviewer

<table>
<thead>
<tr>
<th>View</th>
<th>Reviewer 1</th>
<th>Reviewer 2</th>
<th>Reviewer 3</th>
<th>Reviewer 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-chamber</td>
<td>89</td>
<td>73</td>
<td>90</td>
<td>93</td>
</tr>
<tr>
<td>LVOT</td>
<td>66</td>
<td>63</td>
<td>76</td>
<td>65</td>
</tr>
<tr>
<td>RVOT</td>
<td>78</td>
<td>76</td>
<td>78</td>
<td>72</td>
</tr>
<tr>
<td>Stomach</td>
<td>91</td>
<td>83</td>
<td>96</td>
<td>93</td>
</tr>
<tr>
<td>SVC-IVC</td>
<td>66</td>
<td>65</td>
<td>85</td>
<td>77</td>
</tr>
<tr>
<td>Ductal arch</td>
<td>61</td>
<td>38</td>
<td>77</td>
<td>68</td>
</tr>
</tbody>
</table>

Data are presented as percentages.
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Table 2. Concordance of Reviewers’ Judgments Stratified by Type of Cardiac View

<table>
<thead>
<tr>
<th>View</th>
<th>1 vs 2</th>
<th>1 vs 3</th>
<th>1 vs 4</th>
<th>2 vs 3</th>
<th>2 vs 4</th>
<th>3 vs 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-chamber</td>
<td>80</td>
<td>91</td>
<td>88</td>
<td>75</td>
<td>78</td>
<td>87</td>
</tr>
<tr>
<td>LVOT</td>
<td>85</td>
<td>78</td>
<td>83</td>
<td>79</td>
<td>80</td>
<td>79</td>
</tr>
<tr>
<td>RVOT</td>
<td>80</td>
<td>76</td>
<td>78</td>
<td>76</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>Stomach</td>
<td>90</td>
<td>95</td>
<td>92</td>
<td>87</td>
<td>88</td>
<td>95</td>
</tr>
<tr>
<td>SVC-IVC</td>
<td>67</td>
<td>69</td>
<td>69</td>
<td>72</td>
<td>74</td>
<td>78</td>
</tr>
<tr>
<td>Ductal arch</td>
<td>63</td>
<td>70</td>
<td>79</td>
<td>59</td>
<td>66</td>
<td>73</td>
</tr>
<tr>
<td>Complete examinationa</td>
<td>69</td>
<td>71</td>
<td>77</td>
<td>64</td>
<td>68</td>
<td>66</td>
</tr>
</tbody>
</table>

Data are presented as percentages.

aSatisfactory 4-chamber, LVOT, RVOT, and stomach.

Discussion

In the quest to discern more reliable methods for population-based sonographic screening of the fetal heart, investigators have suggested that 3D imaging could provide a solution. One type of 3D imaging, sonoVCAD, has several theoretical advantages over traditional screening as well as other 3- and 4-dimensional technologies. First and foremost, the sonographer only needs to be able to obtain a volume at the level of the apical 4-chamber view to generate all the other views that are desired for a complete screening examination. Moreover, once that 4-chamber view is acquired, automated software can be used to obtain the desired outflow views, thereby blunting the effects of human limitations. Last, because stored 3D volumes can be manipulated, an experienced sonologist can attempt to acquire and assess the full set of screening views after a patient has left the ultrasound laboratory, thereby allowing a greater number of patients to be examined.

Despite the theoretical advantages, however, the benefits of sonoVCAD have not been demonstrated in a general population of parturients undergoing screening sonographic examinations in the second trimester. Although some investigators have evaluated sonoVCAD and illustrated that it can result in a relatively high frequency of adequate screening examinations, there remains uncertainty as to the generalizability of their findings. Abuhamad8 notes in his discussion that the sonographers and sonologists in his study tended to obtain 3D volumes in patients that imaged adequately in 2D. Uittenbogaard et al,11 on the other hand, attempted to obtain 3D volumes in consecutive patients regardless of how they imaged in 2D. The results of our study were similar to those of Uittenbogaard et al; only 43% to 65% of the studies were satisfactory for screening. This is consistent with our previously published study of 3D fast acquisition volume imaging, which showed that approximately 50% of 3D volumes were of sufficient quality to be satisfactory for screening.12

We incorporated several aspects into this study design to assess how sonoVCAD may function when used for a general obstetric population. The performance of 3D imaging was not contingent on demonstrated ability to obtain adequate 2D images, and women of varying body types were enrolled. It should be noted that we did exclude women above a BMI of 35 kg/m², given that image quality is well known to be reduced among parturients with higher BMIs, and we did not wish to include a population that would so substantially bias the results of the study. Additionally, multiple reviewers were employed to limit the bias that could be introduced by basing conclusions on one person’s judgment.
With this methodologic approach, our study has revealed that 3D acquisition of fetal cardiac views with sonoVCAD in the second trimester may not fully solve the problem of inconsistently obtained adequate screening examinations. Higher satisfactory screening rates were seen for the stomach view (83%–96%) and the 4-chamber view (73%–93%). These rates approach 90% or better if the scores of reviewer 2 are not included. Reviewer 2 noted discomfort with not being able to look at real-time clips of the 4-chamber view, which was her standard custom for screening. This suggests that the initial scanning plane was satisfactory for most patients in this study. The remaining views, LVOT, RVOT, SVC-IVC, and ductal arch, all had lower rates of satisfactory screening (see Table 1). Moreover, completing a satisfactory screening examination (4-chamber, stomach, LVOT, and RVOT views) was only possible, depending on different reviewers' judgments, in 43% to 65% of patients. Although there was some discordance among reviewers as to whether a given image or examination was satisfactory, it does not appear that the results were primarily dependent on one reviewer's particular judgment. For most images, the reviewers had similar frequencies with which they judged images to be satisfactory and had relatively high levels of concordance as to their judgments (Tables 1 and 2, respectively). However, it is clear from our previous publication that individual graders can vary in their scoring of cardiac images. A similar finding has been reported in the nuchal screening literature.

A legitimate concern with this study design is that it was biased against showing how well the VCAD software performs. It is clear from the logistic regression that a higher percentage of scans would have been satisfactory if obese patients or patients in whom the fetal spine position was anterior were excluded. However, to exclude these groups does not test the applicability of 3D fast acquisition as a screening technique in a typical clinic setting. Our clinical experience confirms that the VCAD software performs very well in extracting the screening views when high-quality volume sets are available, but clearly obesity and fetal spine-anterior positions are major issues in obtaining high-quality imaging in both 2D and 3D.

A second concern is that the study design did not evaluate the quality of the 2D imaging in these fetuses. In 2D imaging when a fetus is persistently spine anterior, a window is searched for by using the curvature of the pregnant abdomen to image the 4 chambers and outflows. A similar technique can be used in 3D imaging, but it appears more subject to shadowing artifacts.

### Table 4. Results of Logistic Regression for Association With a View That Was Unsatisfactory for Screening

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obese</td>
<td>3.0</td>
<td>1.7–5.0</td>
</tr>
<tr>
<td>Placenta anterior</td>
<td>0.73</td>
<td>0.50–1.1</td>
</tr>
<tr>
<td>Fetal spine anterior</td>
<td>1.7</td>
<td>1.1–2.5</td>
</tr>
</tbody>
</table>

This study also reveals some factors that may be responsible for degradation of 3D image quality and the relatively low frequencies of satisfactory screening examinations that were obtained in this study. First, this study shows the inverse relation that the BMI has with image quality. This inverse relation has been shown with respect to 2D imaging and, not surprisingly, is also present for 3D imaging. The population-wide trend toward higher BMIs bodes poorly for adequate sonographic imaging and will not be easily overcome even with sonoVCAD. Additionally, a position of the fetus with the spine toward the maternal abdomen also reduces the odds of obtaining a satisfactory cardiac 3D screening examination. This factor is potentially modifiable, although its alteration may require additional patient visits and use of resources.

It is possible that higher overall satisfactory screen rates would have been obtained if both an apical as well as a subcostal approach to volume acquisition had been taken. This study chose an apical approach because it requires very little software manipulation to then properly align the 4-chamber view into the 4-chamber frame during the initial steps of applying the VCAD software. With an anterior chest position, an apical volume places the angle of insonation at 30° to 45° to the intraventricular septum. With a subcostal approach, the angle of insonation is perpendicular, which can provide better axial resolution. This will need to be evaluated in future studies.
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Given our study design, it is not possible to state with certainty the percentage of time that fetuses that remain persistently spine anterior can be satisfactorily screened in 2D. Because 30% of the fetuses in this study remained persistently spine anterior, this is a clinically relevant question that warrants further study.

Although we used a study design that attempted to provide generalizable findings, it should be noted that the study did occur in a level III perinatal center with a high obstetric sonography volume. Additionally, all the reviewers are experienced perinatal sonographers. The bias that would be introduced by these circumstances, however, would be toward showing a greater benefit of sonoVCAD, not underestimating its utility. Also, this study does not necessarily indicate that sonoVCAD cannot be a useful adjunct to 2D imaging. Although we believe it will, it still remains to be determined by evidence-based studies whether, and to what extent, the 3D technique can allow marginal improvements over 2D imaging in obtaining satisfactory screening examinations. This is particularly relevant for laboratories with less perinatal experience in obtaining cardiac views.

There is little doubt that sonoVCAD is a promising technology with multiple potential applications. It is likely that rapid progress in volume acquisition with high-resolution electronically steered matrix probes will occur in the next 5 to 10 years. Sonographically based volume computer-aided analysis has shown the possibilities of tomographic imaging of the fetal heart with computer-aided analysis and may provide progressively more enhanced imaging. Several investigators have attempted to use 4-dimensional spatiotemporal image correlation (STIC) for prenatal screening in the second trimester. Spatiotemporal image correlation has the advantage of offering a gated cardiac cycle but requires the fetus to remain motionless for up to 15 seconds in the absence of good tracking mechanisms; otherwise, it is subject to motion artifacts and also has degraded images when the fetus is in the back-up position. Uittenbogaard et al. have shown that the acquisition of STIC volumes requires expertise. The combination of STIC and VCAD for screening warrants further investigation. Further advances and evaluations should help elucidate the techniques that are most useful in allowing satisfactory cardiac screening and clarify the conditions under which screening images are most optimal.

References


