Unlike computed tomography and magnetic resonance imaging, ultrasonography is an operator-dependent imaging modality. Two-dimensional (2D) ultrasonographic images are obtained by manual positioning of the transducer, and the quality of such images is dependent on the technical skills and expertise of the sonographers and sonologists performing the ultrasound examinations. This manual process of generating images in 2D ultrasonography results in a lack of standardization and consistency of diagnosis. Furthermore, the variable position of the fetus within the uterus adds some technical difficulty to obstetric ultrasonography. Several studies have documented that the efficacy of obstetric ultrasonography, especially with regard to the detection of fetal abnormalities, is dependent on the expertise of the operator, and a significant difference in the detection of fetal abnormalities has been reported between tertiary and non–tertiary care centers.\textsuperscript{1-4} For anatomically complex organs, such as the fetal heart, detection of congenital abnormalities has been suboptimal in population-based studies.\textsuperscript{1,5-8} It is generally thought that many women in the United States today receive an obstetric ultrasound examination that is considerably lower in standards than currently recommended by various professional societies.\textsuperscript{9,10}

The recent introduction of 3-dimensional (3D) ultrasonography to clinical practice provided an important advance in imaging technology. With 3D ultrasonography, an infinite number of 2D planes of a target volume are acquired. The volume acquired by 3D ultrasonography can be displayed on a monitor in 3 orthogonal planes, representing the sagittal, transverse, and coronal planes of a representative 2D plane within this volume (Figure 1). Such a display of 3 orthogonal planes from a 3D volume acquisition is termed a \textit{multiplanar display}. The multiplanar display of 3D ultrasonographic volumes enables an operator to manipulate the acquired target volume to create and display reconstructed planes within this volume. Despite these recent advances in ultrasonographic imaging, the acquisition, display, and manipulation of 3D volumes is a technique that requires a substantial learning curve. Even for well-trained personnel, 3D volume manipulation can be diffi-
cult to perform, particularly when the volume involves relatively complex anatomic organs such as the fetal central nervous system and the fetal heart.

Two important concepts of 3D multiplanar display need to be highlighted given its relevance to the discussion at hand. First, the acquired volume of a particular anatomic structure by 3D ultrasonography, such as a volume of the fetal heart, contains all the anatomic 2D planes for a complete anatomic evaluation of this structure. Second, for every human organ, these 2D planes that are required for a complete anatomic evaluation of that particular organ are organized in a constant anatomic relationship to each other. It is therefore theoretically possible to obtain a volume of a specific organ, such as the fetal heart, and to allow an automated program to display out of this volume all the 2D planes that are required for a complete anatomic evaluation of this organ. We will term this new concept *automated multiplanar imaging* (AMI).

Automated multiplanar imaging will allow for an operator-independent display of relevant 2D ultrasonographic planes out of a volume of a complex structure such as the fetal heart or fetal central nervous system. Automated multiplanar imaging is based on a software program that, for various organs, relates all the standardized planes that are required for a complete anatomic evaluation of a particular organ based on the respective spatial relationship of these planes within a 3D volume. This spatial relationship between standardized planes, which can be mathematically defined by the x-, y-, and z-axes, is constant for each organ. In practical terms, the spatial relationships of the standardized 2D planes of the fetal heart (Table 1) are predetermined, and their respective formulas are entered into a software program. Once a 3D volume of the fetal heart is obtained from the level of a standardized plane, such as the 4-chamber view, for instance, AMI will automatically generate all other standardized planes from the acquired vol-

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**Figure 1.** Multiplanar display of a 3D volume of the fetal heart obtained at the reference level of the 4-chamber view at 20 weeks’ gestation. A, Four-chamber view. B and C, Perpendicular planes within the volume from reference plane A.
volume in an operator-independent method. The constant anatomic relationship of these standardized planes to each other will allow for excellent reproducibility of AMI-generated ultrasonographic images. Automated multiplanar imaging will thus allow for a complete evaluation of anatomically complex organs with a standardized and operator-independent approach. In Figure 2, a 3D volume of the

Table 1. Standardized Ultrasonographic Views of the Fetal Heart

<table>
<thead>
<tr>
<th>View</th>
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<tbody>
<tr>
<td>4-chamber view</td>
</tr>
<tr>
<td>Right ventricular outflow tract</td>
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<tr>
<td>Left ventricular outflow tract</td>
</tr>
<tr>
<td>3-vessel view</td>
</tr>
<tr>
<td>Aortic arch view</td>
</tr>
<tr>
<td>Ductal arch view</td>
</tr>
<tr>
<td>Venous connections (IVC-SVC)</td>
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IVC indicates inferior vena cava; and SVC, superior vena cava.

Figure 2. A, Reference plane of a 3D volume of the fetal heart obtained at the 4-chamber view at 20 weeks’ gestation. B–F, Images automatically generated by AMI from the 3D volume obtained at the 4-chamber view (A).
fetal heart was obtained at the reference level of the 4-chamber view in a fetus at 20 weeks’ gestation (Figure 2A); AMI was used to generate out of this volume all other standardized planes depicted in Figure 2, B–F.

By standardizing the approach to image acquisition and display and by substantially reducing the possibility of human error, AMI will improve the diagnostic acumen of ultrasonographic imaging and thus will prove advantageous to clinical practice. Automated multiplanar imaging will also improve the efficiency of ultrasonographic imaging by reducing the time needed to complete an ultrasound examination, thereby resulting in increased throughput at ultrasound laboratories.

These bold predictions will need to be substantiated by several research studies that address the practical applicability of AMI in today’s clinical practice. The initial phases of these studies are under way.

References


