Manufacturing Models of Fetal Malformations Built From 3-Dimensional Ultrasound, Magnetic Resonance Imaging, and Computed Tomography Scan Data

Heron Werner, PhD,*† Liliam Cristine Rolo, PhD,‡ Edward Araujo Júnior, MD, PhD,‡ and Jorge Roberto Lopes Dos Santos, PhD§

**Abstract:** Technological innovations accompanying advances in medicine have given rise to the possibility of obtaining better-defined fetal images that assist in medical diagnosis and contribute toward genetic counseling offered to parents during the prenatal period. In this article, we show our innovative experience of diagnosing fetal malformations through correlating 3-dimensional ultrasonography, magnetic resonance imaging, and computed tomography, which are accurate techniques for fetal assessment, with a fetal image reconstruction technique to create physical fetal models.

**Key Words:** fetal malformations, manufacturing methods, 3-dimensional ultrasound, magnetic resonance imaging, computed tomography

(Ultrasond Quarterly 2014;30:69–75)

Technological innovations accompanying advances in medicine have given rise to the possibility of obtaining better-defined fetal images, which has made it easier to identify and comprehend fetal abnormalities that may be present, while still in the intrauterine environment. In this manner, fetal imaging not only assists in medical diagnosis but also contributes toward genetic counseling offered to parents during the prenatal period, which promotes better selection of therapeutic management when this is possible. Currently, ultrasound is the primary method for fetal assessment during pregnancy because it is patient friendly, useful, and cost-effective and considered to be safe. Fetal 3-dimensional (3D) images can be obtained by 3D ultrasonography (3DUS) in rendering mode, magnetic resonance imaging (MRI), and computed tomography (CT).

From the images obtained through these technologies, with automated image reconstruction, it has become possible to create physical models for normal fetuses and for fetuses with malformations.1,2

Thus, this pictorial essay had the aim of illustrating images of fetuses with malformations that were identified through these methods during prenatal assessments.

**Description of the Technique**

All fetuses examined in the present study initially underwent ultrasonography screening first. The ultrasonography apparatus used was equipped with endovaginal and/or transabdominal high-resolution transducers (4–8 MHz) (Voluson 730 Pro/Expert; General Electric Medical Systems, Zipf, Austria).

Subsequently, for better viewing and diagnostic clarification, and depending on the fetal malformation observed on ultrasonography, the imaging examination was supplemented with MRI or CT. For example, in cases of soft tissue, thoracic, or central nervous system abnormalities, MRI was used, whereas in cases of skeletal dysplasia, CT was used.

Because MRI does not present radiation, it can be used without contraindications during pregnancy. Its diagnostic accuracy improves with increasing gestational age and is not disturbed by marked oligohydramnios, maternal obesity, or fetal static, which are responsible for low image quality on ultrasound.3 However, CT subjects the fetus to radiation and for this reason is indicated only when there is a need for better clarification of skeletal and thoracic abnormalities that were inadequately observed on ultrasonography.

Magnetic resonance imaging was performed using apparatus with a 1.5-T scanner (Magnetom Avanto and Aera; Siemens, Erlangen, Germany). The protocol used was T2-weighted sequence (half fourier acquisition single shot turbo spin echo; repetition time shortest, time to echo 140 milliseconds; field of view = 300–200 mm; matrix 256 × 256; slice thickness 4 mm, 40 slices, and acquisition time 18 seconds in 3 planes of the fetal body). In addition, we applied 3D T2-weighted true fast imaging with steady-state precession (TrueFISP) sequence in the sagittal plane (repetition time 3.02 milliseconds, time to echo 1.34 milliseconds, voxel size 1.6 × 1.6 × 1.6 mm³, fractional anisotropy 70, parallel acquisition techniques 2) with 96 to 136 slices of thickness 1.0 to 1.6 mm and acquisition time of 26 seconds. The total duration of the examination did not exceed 40 minutes.

To perform CT, 64-channel multislice scanner was used (Philips, Solingen, Germany) with the following parameters: 40 mAs, 120 kV, 64 slices per rotation, 0.75 pitch, and 0.75-mm slice thickness. The mean radiation dose received by the fetus was 3.12 mGy.
To construct the physical model from 3DUS, MRI, and CT, the first step was to create the 3D virtual model. All the images generated through 3DUS, MRI, and CT were exported to a workstation in DICOM format. Following this, segmentation was performed by a 3D modeling technician, under supervision by the doctor responsible for the case using a digital high-definition screen tablet (Cintiq Wacon, Tokyo, Japan).

The 3D structure of the fetus was reconstructed by generating its surface using software with the capacity to convert the images obtained into numerical models (Mimics v.12; Materialize, Leuven, Belgium). These reconstructed images were then exported using STL (standard triangular language) and were converted to the file extension “OBJ” to use 3D polygonal modeling software (Autodesk Mudbox, San

FIGURE 1. Conjoined twin. Three-dimensional ultrasound imaging (A), MRI (B), photograph of the fetuses after birth (C), and image from the virtual automated reconstruction technique using the combined methods (D).

FIGURE 2. Encephalocele (white arrows). Three-dimensional ultrasound (A), MRI (B), and physical model constructed by means of rapid prototyping (C).
FIGURE 3. Sacrococcygeal teratoma (white arrows). Three-dimensional ultrasound and MRI (A), image from the virtual automated reconstruction technique (B), and physical model constructed (C).

FIGURE 4. Cervical lymphangioma (white arrows). Two-dimensional ultrasound (white arrow) (A), 3DUS (white arrow) (B), image from the virtual automated reconstruction technique (C), physical model constructed (D), and photograph of the fetus after birth (E).
Francisco, Calif). This software determined the volumetric surface of the image for analysis and subsequent topographic comparison. Following this, the 3D model was converted back to the “STL” extension and was exported to the Mimics software, which correlated the shapes and outlines observed from 3DUS, MRI, and CT with the 3D images that were created.

The final processing to determine the physical model of the fetus consisted of guiding UV spot laser beams through a reservoir of photosensitive resin to model the fetal shape based on the data stored in the 3D geometry software, which are sliced into individual transverse planes of predefined thickness, of between 0.1 and 0.2 mm. By moving the laser beam in the $x$ and $y$ axes in a special chamber containing resin composed of photosensitive polymers, the fetal shape was constructed successively, layer by layer on a support platform located directly above the reservoir surface, after hardening of the liquid photopolymer and gradual lowering of the prototype construction platform.

In the following, in the form of a pictorial essay, we describe a variety of fetal malformations using 3DUS, MRI, CT, and the physical models constructed (Figs. 1–9).

**Advantages and Other Applications**
Both MRI and 3DUS provide similar information to the final physical model. The MRI has some advantages in cases
with low amniotic fluid index; however, the US has some advantages in the assessment of fetal surface structures.

Other possible application of the physical model constructed is the capacity to subtract the fetal skin surface showing the internal organ. Werner et al described a new technique named virtual bronchoscopy using data from MRI. The authors described the new technique in a normal fetus at 28 weeks of pregnancy in whom it was possible to perform virtual bronchoscopy to visualize the upper respiratory tract from the pharynx downward through the tracheobronchial tree.

**FIGURE 7.** Cleft lip. Three-dimensional ultrasound (A), image from the virtual automated reconstruction technique (B), physical model constructed (C), and photograph of the fetus after birth (D).

**FIGURE 8.** Apert syndrome. Three-dimensional ultrasound of the face (A), image from the virtual automated reconstruction technique (B), and photograph of the face after birth (C), 3DUS of the hand (black arrow) (D), MRI of the hand (black arrow) (E), and photograph of the hand after birth (D).
with a quality similar to that which could be obtained by videotaped bronchoscopy. In another article, Werner et al described the virtual bronchoscopy to 4 cases of fetal cervical tumors (3 lymphangiomas and 1 teratoma) using data from MRI. In all fetuses, fetal airway patency was clearly demonstrated by virtual bronchoscopy, and this was confirmed postnatally. In Figure 10, we present a case of fetal cervical lymphangioma showing the mass and its relationships with the lungs, beyond the traditional physical model.

A limitation of this technique is that some physical models do not present high-quality images to some fetal malformations as 3DUS or MRI; however, this technique still is in the begging, and we believe that some improvements are necessary. In the future, we believe that physical models can help the doctors to better understand some fetal malformations possibly to make decisions and better counseling of parents.

CONCLUSIONS

Although this is a more complex and relatively costly method, the techniques for 3D viewing demonstrated in this study show the possibilities for manipulating the physical characteristics of malformed fetuses, along with their spatial relationships. Thus, through comparisons with traditional images, the models generated represent an important means of communication both for doctors and for the parents, and especially for visually impaired individuals, for whom the physical model would represent an important means for
comprehending the fetal abnormality. The model would even be of assistance for teaching purposes.2,7,8

REFERENCES