Three-dimensional ultrasonography in the first trimester of human pregnancy

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Our purpose was to visualize normal embryonal and fetal surface anatomical structures in the first trimester of human pregnancy by use of three-dimensional ultrasonography with a specially developed abdominal three-dimensional transducer. Four embryos and 31 fetuses of 8–13 weeks gestation were studied with a specially-developed abdominal three-dimensional transducer (3.5 MHz). This imaging system can provide conventional two-dimensional ultrasonography images and can also generate, within seconds, high-quality three-dimensional images in the surface and transparent mode with no need for an external workstation. The percentage of surface anatomical structures visualized at each gestational age interval using two-dimensional and three-dimensional ultrasonography is presented. Head and trunk were depicted in all cases. The number and the clarity of visualization of face, upper and lower extremities, hand, and foot increased with advancing gestation. The free loop of the umbilical cord was depicted in most cases. The number of depictions of abdominal cord insertion, midgut herniation, and yolk sac decreased with the increase of gestation. Genitals could not be identified in the first trimester. The ability to view some surface anatomical structures (face, hand, and foot) was better with three-dimensional ultrasonography than with two-dimensional ultrasonography. Three-dimensional ultrasonography provides a novel means for visualization of surface anatomical structures of the embryo and early fetus. These results suggest that three-dimensional ultrasonography can become an important modality in future embryological and early fetal research and in detection of embryonic and fetal developmental disorders in the first trimester of pregnancy.

Key words: 2-D ultrasonography/3-D ultrasonography/embryo/fetus/first trimester

Introduction

The embryonic period, which ranges from 4 to 8 weeks after the last menstrual period, is important for human development because the beginnings of most major anatomical structures develop during these 5 weeks. By the end of the embryonic period most major organ systems have been formed (Moore, 1982). Detailed assessments for the sequential appearance of embryonic structures by means of transvaginal ultrasonography have been reported (Warren et al., 1989; Timor-Tritsh et al., 1988, 1989, 1990, 1991; Dolkart and Reimers, 1991). Recently, Fujiwaki et al. (1995) demonstrated that intrauterine ultrasonography could reveal embryonal structures 1–3 weeks earlier than transvaginal ultrasonography. Images of the embryo’s outer configuration might be better with embryoscopy (Quintero et al., 1993). However, the latter two techniques are invasive diagnostic procedures and their safety has not been established.

Three-dimensional (3-D) ultrasonography allows visualization of fetal malformations in all three dimensions at the same time, providing an improved overview and a more clearly defined demonstration of adjusted anatomical planes (Merz et al., 1995a,b). Experience with the visualization of normal embryonic anatomy by 3-D scanning has now provided some authors with the experience and confidence to recognize fetal malformations in the first and early second trimesters (Feichtinger, 1993; Bonilla-Musoles et al., 1995; Bonilla-Musoles, 1996). However, to the best of our knowledge, a detailed description of normal embryonal and fetal surface structures in the first trimester of pregnancy has not yet been published. The objective of the current study was to attempt a systemic look for normal embryonal and fetal surface anatomy in the first-trimester pregnancy by 3-D ultrasonography with a specially developed abdominal 3-D transducer.

Materials and methods

Four embryos and 31 fetuses of 8–13 weeks gestation were studied with specially developed abdominal 3-D ultrasonography transducer (Aloka ASU-1000B, 3.5 MHz, Aloka, Tokyo, Japan). This ultrasonic transducer is connected to an ultrasonography device (Aloka SSD-1700, Aloka). This imaging system can provide conventional two-dimensional (2-D) ultrasonographic images and can also generate, within seconds, high-quality 3-D images in the surface and transparent mode with no need for an external workstation. Subjects with multiple pregnancies or mole pregnancies were excluded from the study. All subjects were evaluated in a cross-sectional manner. Gestational age was estimated from the first day of the last menstrual period and confirmed by first trimester ultrasound examinations. The study was approved by the local ethics committee of Shimane Medical University, and standardized informed consent was obtained from each mother.

A 3-D image is built by selecting a region of interest from a 2-D image and superimposing on the 2-D image a volume box defined by the examiner. The crystal array of the transducer then sweeps mechanically over the 2-D region selected through a 60° angle. Within 5 seconds, the outlined volume is automatically scanned and a sculpture-like 3-D image is displayed simultaneously on the screen. At present we use a
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Figure 1. The whole view of embryo at 8 weeks 5 days. Crown–rump length = 1.8 cm. H = head; LLB = lower limb bud; MH = midgut herniation; ULB = upper limb bud; YS = yolk sac.

Figure 2. Fetus at 9 weeks. Crown–rump length = 2.2 cm. (A) Lateral view; (B) lateral view. H = head; LE = lower extremity; MH = midgut herniation; UE = upper extremity. Gestational ages are expressed in weeks and days.

Figure 3. Fetus at 10 weeks. (A) Oblique view, crown–rump length (CRL) = 3.3 cm; (B) oblique view, CRL = 3.5 cm; (C) lateral view of head, CRL = 3.5 cm; (D) lateral view, CRL = 3.5 cm. MH = midgut herniation. Gestational ages are expressed in weeks and days.
Figure 4. Fetus at 11 weeks. (A) Frontal view, crown–rump length (CRL) = 3.8 cm. Both hands are in front of fetal face. (B) Whole view of fetus, CRL = 4.4 cm. Arrow shows the abdominal cord insertion. (C) Lateral view. CRL = 4.4 cm. Gestational ages are expressed in weeks and days.

Figure 5. Fetus at 12 weeks. Biparietal diameter = 2.1 cm. (A) Frontal view; (B) frontal view of head. H = head. Gestational ages are expressed in weeks and days.

128 Mb removable hard disk drive for the permanent storage of 3-D images.

For each gestational age interval we recorded the number of cases in which a superficial anatomical structure (head, face including eye, nose and mouth, upper extremities, hand, trunk, abdominal cord insertion, midgut herniation, genitals, lower extremities, foot, free loop of cord, and yolk sac) was visualized, and the percentage of anatomical structures at each interval using 2-D and 3-D ultrasonography was calculated. Correlation of the detected structures with the appropriate structure in an embryology textbook (Moore, 1982) was attempted for each gestational age. Visualization of embryonic structures by 2-D and 3-D ultrasonography was compared using Fisher’s exact test (Siegel and Castellan, 1988). A P value of < 0.05 was considered to be statistically significant.

Results
Development of the fetus was recorded as 3-D images (Figures 1–6). By the eighth week the whole embryonal contour could be identified but facial structures were not imaged (Figure 1). By week 9 upper and lower extremities, and midgut herniation were clearly seen, but the face was not yet recognizable (Figure 2). Facial structures, hand, and foot could be identified at 10 weeks (Figure 3). At weeks 11 and 12 (Figures 4 and 5) surface structures became clearer. At week 13 fingers were depicted clearly and the fetus attained a characteristic human appearance (Figure 6).

Table I shows the anatomical structures distinguished at each gestational age interval by 2-D and 3-D ultrasonography. Head and trunk were depicted in all cases. The number and the clarity of visualization of face, upper and lower extremities, hand, and foot increased with advancing gestation. Free loop of the umbilical cord was depicted in most cases. The number of occurrences of visualization of abdominal cord insertion, midgut herniation, and yolk sac decreased with the advance of gestation. Genitals could not be identified in the first trimester. The ability
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Figure 6. Fetus at 13 weeks. (A) Oblique view, biparietal diameter = 2.4 cm. (B) Lateral view, biparietal diameter = 2.4 cm. (C) Lateral posterior view, biparietal diameter = 2.4 cm. (D) Hand and fingers, biparietal diameter = 2.6 cm. (E) The whole view of fetus. Free loop of the cord (arrow) is depicted, biparietal diameter = 2.6 cm. Gestational ages are expressed in weeks and days.

Table I. Percentage of cases in which anatomical structures were visualized at each gestational age by two-dimensional (2-D) and three-dimensional (3-D) ultrasonography

<table>
<thead>
<tr>
<th>Anatomical structures</th>
<th>Gestational age (weeks)</th>
<th>2-D</th>
<th>3-D</th>
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<tbody>
<tr>
<td></td>
<td>8–9.9 (n = 10)</td>
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<td>Head</td>
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<td>100</td>
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<tr>
<td>Face</td>
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<td>0</td>
<td>0</td>
<td>69*</td>
<td>17</td>
<td>58*</td>
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<tr>
<td>Upper extremities</td>
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<td>92</td>
<td>85</td>
<td>100</td>
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<td></td>
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<tr>
<td>Hand</td>
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<td>0</td>
<td>15</td>
<td>54*</td>
<td>25</td>
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<tr>
<td>Trunk</td>
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<td>100</td>
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<td>100</td>
<td>100</td>
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<td>80</td>
<td>77</td>
<td>92</td>
<td>58</td>
<td>50</td>
<td></td>
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<tr>
<td>Mdgt herniation</td>
<td>70</td>
<td>80</td>
<td>50</td>
<td>62</td>
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<tr>
<td>Lower extremities</td>
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<td>60</td>
<td>100</td>
<td>92</td>
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<td>Foot</td>
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<td>38*</td>
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<tr>
<td>Free loop of cord</td>
<td>90</td>
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<td>92</td>
<td>85</td>
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<td>92</td>
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<tr>
<td>Yolk sac</td>
<td>90</td>
<td>90</td>
<td>69</td>
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*P < 0.05; 2-D versus 3-D at each gestational age.

to view some surface anatomical structures, such as face, hand and foot, was better with 3-D ultrasonography than with 2-D.

Discussion

Potential obstetric applications of 3-D ultrasonography for systematic examination of the developmental stages of the embryo and early fetus or detection of embryonal and early fetal malformations have been reported (Feichtinger, 1993; Bonilla-Musoles et al., 1995; Steiner et al., 1995; Bonilla-Musoles, 1996). However, the whole process still takes 5–10 min. In the current study we used a specially developed abdominal 3-D transducer, and this imaging system proved capable of providing conventional 2-D ultrasonography images, while also possessing the capacity to generate within, high-quality fine, 3-D images on the screen with no need for an external workstation (Baba et al., 1996). However, facial structures could not be identified at 8–9 weeks gestation, and image quality was slightly impaired. In the process of embryogenesis, the configuration of embryonic facial structure has not been established at this period (Moore, 1982). Other reasons for these ambiguous visualizations are the small embryonal size and the fact that the transabdominal transducer frequency (3.5 MHz) is relatively low. Use of a transvaginal 3-D probe with high-frequency transducer may
make it possible to obtain finer quality images of very small embryonic structures. However, good quality images of the fetus could be obtained using the transabdominal transducer at 10 weeks gestation.

The embryonic and early fetal periods are important for human development because most major organ systems have been formed by this time (Moore, 1982). Detailed assessments for the sequential appearance of embryonic structures by means of transvaginal ultrasonography have been reported (Warren et al., 1989; Timor-Trisch et al., 1988, 1989, 1990, 1991; Dolkart and Reimers, 1991). However, even under optimal conditions, the complex curvature of the embryo makes it difficult to obtain adequate images with 2-D ultrasonography, and many cross-sectional images are required to obtain a complete impression (Pretorius and Nelson, 1995). Our study demonstrated that 3-D ultrasonography could clearly reveal the surface of the entire embryo and early fetus in the first trimester. However, in this study, genitals could not be recognized in the first trimester of pregnancy. Bonilla-Musoles et al. (1995) identified male fetal genitals as early as week 12, using a transvaginal approach. Use of a transvaginal 3-D probe with high-frequency transducer should make it possible to obtain finer quality images of very small embryonic structures at an earlier stage than with a transabdominal 3-D probe. Unfortunately, at present we do not have a transvaginal 3-D probe for our new 3-D ultrasonographic device; further technical development is awaited.

With respect to limitations associated with 3-D ultrasonography in the first trimester (Bonilla-Musoles et al., 1995), the most common reason for partial observation was active embryonal or fetal movement. Another reason was the proximity of the fetus to the uterine wall or to the placenta. A third barrier to complete visualization is location of the fetal head deep in the pelvis in a direct occipito–anterior position. Moreover, strong curvature of the gestational sac restricted satisfactory visualization of the embryo. These problems with 3-D ultrasound fetal imaging will be resolved as further technical advances are made (Merz et al., 1995b).

In conclusion, 3-D ultrasonography provides a novel means for visualizing surface anatomical structures of the embryo and early fetus. These results suggest that 3-D ultrasonography can become an important tool in future embryological and early fetal research and in detection of embryonic and fetal developmental disorders in the first trimester of pregnancy.

References