3D imaging of the fetal face – Recommendations from the International 3D Focus Group

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Introduction

Three-dimensional and four-dimensional ultrasound (3D/4D US) technology can be easily applied to routine prenatal diagnosis and can provide images of the fetal face that cannot be achieved with two-dimensional ultrasound (2D US) [1–7]. The most recent 3D/4D US technology facilitates the 3D/4D US examinations even for the less trained sonographer and gives the examiner the opportunity to identify the normal and abnormal fetal face in the most appropriate imaging mode [8]. The purpose of publishing these recommendations was to demonstrate the different possibilities of assessing the normal and abnormal fetal face with 3D/4D ultrasound and to give the operator an overview of the benefit resulting from the application of that technology.

Display modes

In contrast to conventional 2D US, which provides only one imaging mode to demonstrate the fetus, 3D/4D US technology offers the ability to review the fetal face in different display modes [7, 8]: 1. three-orthogonal-plane (= triplanar1 or multiplanar1) display, 2. parallel-plane (= tomographic1 or multislice1) display, 3. 3D surface display and 4. 3D transparent display (maximum, x-ray and minimum mode). In addition some ultrasound systems allow also an ‘any plane slicing’ and a mixing of two different modes (eg. mode 1 70 % and mode 2 30 %). Furthermore 4D US allows volume visualization of 3D images of the fetus in real-time.

1. Three-orthogonal-plane display

In this display [7, 8] all three mutually perpendicular planes are displayed simultaneously on the monitor immediately after volume acquisition in 3D or in 4D (real time) US scanning. In this primary 3-orthogonal-plane image (Fig. 1) [9], the object is displayed so that the image at the top left always corresponds to that visualized in the monitor during 2D US scanning. This permits to draw a valid conclusion on the position of the embryo/fetus at the time of volume scanning. Following display of all 3 perpendicular planes the object can be rotated in all 3 dimensions. However, this can lead to a loss in spatial orientation. To avoid such a confusion the ISUOG 3D Focus Group [9] has recommended to rotate the volume in such a way that the embryo/fetus may at all times be visualized in an upright sagittal position in the image at the top right (secondary 3-orthogonal-plane image) (Fig. 2). This ensures that the object of interest is visualized automatically in an anatomically correct position in the coronal and transverse plane, regardless of the possible vertex or breech presentation. With the three-orthogonal-plane display all conventional scan planes can be viewed, as well as planes that are unattainable with traditional 2D US. The simultaneous display of all three perpendicular sectional planes provides an ideal basis for a detailed survey of the fetus and allows the demonstration of a specific 2D plane to be precisely controlled. To optimize the position of the face, the cursor dot should be placed between the orbits in the coronal plane and the face rotated in all planes until it is symmetrical (Fig. 2).

2. Parallel-plane (= tomographic) display

With the parallel-plane display [7, 8] the region of interest can be displayed on the monitor in several parallel slices similarly to CT or MRI (Fig. 3–5). This display enables a detailed tomographic survey of the fetal face in sagittal, coronal and transverse slices at different distances. The sagit-
tal planes are helpful to demonstrate the profile and the orbits, the coronal planes to assess the orbits and the palate and the transverse planes to evaluate the orbits, palate, maxilla and mandible.

3. 3D surface display
This display mode [7, 8] provides three-dimensional surface images of the fetal face (Fig. 6, 7). There are different rendering (calculation) algorithms to depict the fetal face: surface mode, soft surface mode, light mode, and soft light mode (Fig. 8). Two of these modes can be mixed in different percentages.

The prerequisites for high-quality 3D US images of the fetal surface are the presence of a sufficient amniotic fluid pocket in front of the structure being imaged and the absence of overlying or adjacent structures [2]. However, in some cases the face is hidden by overlying or adjacent structures. In order to obtain a high-quality surface image those structures have to be removed with the electronic scalpel [10]. This tool allows the examiner to remove most of the overlying structures in any of the slice images, or in the 3D image itself. However, when overlying structures (e.g., limb bones) create acoustic shadows, the electronic scalpel cannot overcome those artifacts. The best surface images can be achieved when the fetal face is looking towards the probe, when there is enough amniotic fluid in front of the face and when there are no overlying structures causing shadows.

4. Transparent display
In terms of the different transparent modes (maximum mode, X-ray mode), the maximum mode (= maximum intensity display) [7, 8, 11–13] can be used to visualize hyperechogenic structures. This mode provides a complete survey of the fetal skull and facial bones (Fig. 9). To get high quality pictures this mode can be mixed with surface mode.

**Fig. 1** Three-orthogonal-plane display of a fetus in breech presentation at 25 weeks of gestation. Primary 3-orthogonal-plane image after acquisition. Plane a = sagittal plane. Plane b = transverse plane (bird’s eye view). Plane c = coronal plane (= frontal view). Plane a demonstrates the 2D US image during acquisition. le = left, ri = right.

**Fig. 2** Secondary 3-orthogonal-plane image after rotation the fetus of Fig. 1 into an upright position and horizontal rotation of 90°. Plane a = coronal plane at orbit level. Plane b = median plane. Plane c = transverse plane at orbit level. This demonstration shows the fetal face always in an anatomically correct position: le = left, ri = right.

**Fig. 3** Parallel-plane (= tomographic) display showing several slices of the fetal face at distances of 5.0 mm (sagittal views). 23 weeks of gestation.
4 D ultrasound (= real time 3 D US) [7, 8]  

4 D US technology allows real time visualization of the fetus in any of the modes described above. In particular, with fast acquisition of up to 35 volumes per second, both the surface and movements of the fetus can be demonstrated constantly on the screen. This enables the physician to study fetal facial movements such as yawning, sucking, swallowing, mimicking [9] and offers the parents the opportunity to observe fetal movements. From the diagnostic point of view 4 D US is always helpful in the moving fetus, and 3 D US in the fetus at rest.

3 D US imaging of the fetal face in the first trimester (11 – 14 weeks of gestation)

Normal anatomy

In the first trimester 3 D US can be applied for the profile and for demonstration of normal ossification (Table 1). While the profile with nose, lips and chin can be shown with the three-orthogonal-plane display and a 3 D US surface rendered image as well (Fig. 10), the demonstration of the nasal bone [14, 15] and the frontomaxillary facial (= FMP) angle [16, 17] is performed using the 3-orthogonal-plane display (Fig. 11, 12). To demonstrate
the nasal bone in the first trimester correctly, it is necessary to use a slightly parasagittal section, because the left and right nasal bone are not fused yet (Fig. 11). A true median view, however, reveals the gap between the two nasal bones and can therefore lead to the false diagnosis of absent nasal bone [18]. In comparison to 2D US the 3D scan is an excellent method to either demonstrate the nasal bone correctly or to find out absent nasal bone precisely.

In a detailed ultrasound examination for demonstration or exclusion of a fetal face malformation two images are recommended for documentation: a sagittal view with profile in a rotation of 45° and the measurement of the FMF-angle (Table 1).

Early detection of malformations of the fetal face
Absence of nasal bone [14, 15, 19] and increased FMF-angle (> 85°) [17] in the first trimester are important screening signs for possible trisomy 21. However, absent nasal bone is also found in 2.6% of euploid fetuses. Prevalence of absent nasal bone is affected not only by the fetal karyotype but also by maternal ethnicity, being higher in black than in white women [19]. Because some healthy fetuses show a delayed ossification of the facial bones it is recommended not to evaluate these two parameters before 12 weeks of gestation.

Using advanced ultrasound systems anomalies such as micrognathia, hypo- and hypertelorism, cleft lip and palate, can be diagnosed in some fetuses in the first trimester although there is much more experience in the second trimester (see below).

3D US imaging of the face, orbits, nasal bone, palate, maxilla and mandible in the second and third trimesters

Normal anatomy
In the second and third trimesters 3D US can be applied for the demonstration of the surface of the fetal face [1, 2, 7] (Fig. 6 – 8) and for the demonstration of a normal ossification of the facial bones as well [12] (Fig. 9). As in the first trimester the profile with the nose, lips and chin are shown in the 3-orthogonal plane display (Fig. 1, 2) and in the 3D surface rendered image as well. Orbits and lenses are easily compared in the coronal and transverse planes in the 3-orthogonal-plane display (Fig. 2). These planes can also be used to measure the orbit diameters and the inner and outer orbital distances. Measurement of the FMF-angle [16] can be performed as in the first trimester [17] (Fig. 12). Demonstration of the nasal bone is much easier, because both nasal bones are now fused and can be shown in a slightly parasagittal and in the median plane as well. The nasal bone can be shown

Table 1 Assessment of the fetal face by 3D US in the first trimester.

<table>
<thead>
<tr>
<th>1. Anatomy (3-orthogonal-plane display/3D surface display/transparent [maximum intensity display])</th>
<th>median (sagittal view)</th>
<th>parasagittal view</th>
<th>coronal view</th>
<th>transverse view</th>
</tr>
</thead>
<tbody>
<tr>
<td>profile with forehead, nose, lips and chin</td>
<td>nasal bone present/absent (demonstration of the face with an angle of 45°, nasal bone parallel to the upper image margin), orbits and lips</td>
<td>forehead, orbits, both nasal bones, maxilla and mandible</td>
<td>forehead, orbits, both nasal bones, maxilla and mandible</td>
<td></td>
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</tbody>
</table>

| 2. Biometry sagittal view | frontomaxillary facial angle (= FMF-angle) (> 85°) (maxilla parallel to the upper image margin) |
| 3. Image Documentation | profile with nasal bone – FMF-angle (optional) |

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Fig. 7 Three-orthogonal-plane display and 3D US surface rendered image of a fetus at 23 weeks of gestation after rotation the face into an upright position (upper left). Upper right: The volume box for rendering the region of interest is positioned close to the surface of the left side of the face (reverse view). The green arrow and the green line demonstrate the camera position. Lower left: View of the orbits from a bird’s eye view. le = left, ri = right. Lower right: A surface-rendered image of a fetal face (side view) in profile.

Fig. 8 Different surface displays of a fetus at 23 weeks of gestation. a = surface mode, b = soft surface mode, c = soft light mode, d = light mode.
with the 3-orthogonal-plane display and also with the maximum intensity (transparent) display. Measurement of the nasal bones can be performed in the sagittal and coronal plane as well. Demonstration of the palate is best performed by acquiring the volume so that the palate is not shadowed by other facial structures. This can be easily done in the sagittal plane while the head is tipped posteriorly. The palate can be shown from three different views using maximum intensity display: from a front view (Fig. 13), from a ‘reverse face’ view [20] (Fig. 14) or from a bottom view inside the mouth [21] (Fig. 15). For that purpose, a thin volume box is applied in the sagittal image of the 3 orthogonal planes as shown in Fig. 13 – 15. Further approaches to demonstrate the secondary palate are the ‘flipped face view’ technique [22, 24] and the angled insonation technique [23, 24] where the secondary palate is insonated at 45° angle in the sagittal plane and 3D US is used to reconstruct axial and coronal planes. Another option is to demonstrate the secondary palate in the 3D US surface rendered display by cutting the frontal part of the fetal face with the electronic scalpel [8, 10] (Fig. 16) or by placing the volume box inside the fetal face (Fig. 16).

Detection of fetal face anomalies
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Simultaneous display of all three orthogonal sectional planes (3-orthogonal-plane display) is particularly helpful in the verification of an exact mid-sagittal section (= median plane), which is required to reliably identify a flat facial profile or micrognathia [2, 6, 7, 8, 18, 25]. In addition, mid-facial hypoplasia [26] or absence of the nasal bone [11] can be detected accurately and should serve as an indication for invasive testing for trisomy 21. The coronal and transverse planes allow the comparison of the orbit diameters and a conclusive demonstration of eye malformations. In order to avoid confusion regarding the accurate anatomical assignment of left/right and dorsal/ventral, it is helpful to use a standardized 3-orthogonal-plane display [9].

The parallel-plane (= tomographic) display can be useful in the demonstration of facial malformations as, e.g. hyper-/hypotelorism, orbital dysplasia, cataract, cleft lip and cleft palate. By selecting the number of parallel slices and the distance between the slices, the acquired region of interest (ROI) can be displayed on the monitor at different numbers of 2D US images, which provides a precise overview of the entire range of the acquired volume [7]. Surface rendered images accurately demonstrate all malformations on the surface of the fetal face either in a side or a frontal view: frontal bossing, flat profile, cyclopia with proboscis, cleft lip, micrognathia [2, 6]. Rendering of multiple 3D US images (cine sequence) gives an excellent spatial depiction of the severity of a defect, as this can be viewed from different angles. For the
differentiation between isolated cleft lip and cleft lip with cleft palate, it is necessary to remove the frontal aspect of the fetal face electronically or to place the volume box inside the fetal face (Fig. 16). This procedure enables an assessment of the fetal palate by providing an inner surface view, which enables the ready detection of a palatal defect. The diagnosis of cleft palate can also be established by different 3D US procedures as described by Campbell et al. [20], Benacerraf et al. [21], Platt et al. [22], Pilu et al. [23] and Ramos et al. [24]. The reverse face view [20] is also useful to detect anophthalmia [27].

Despite the fact that the different display modes enable an excellent demonstration of the fetal face there are a few situations that can cause problems [30]: 1. Fetal or probe movements during data acquisition lead to motion artifacts (Fig. 18), 2. surface rendering cannot be done in severe oligohydramnios, 3. overlying or adjacent structures interfere with surface rendering and must first be removed with the electronic scalpel, 4. arms or legs in front of the fetal face can cause shadowing artifacts defects because of the long bones, 5. setting the threshold too high or faulty manipulation of the electronic scalpel leads to iatrogenic structural defects and 6. the surface display of the fetal face in the early embryologic development (first trimester or beginning of the second trimester) does not show the typical human facial appearance as observable in the late second or in the third trimester and this should not be misinterpreted as a malformation of the fetal face.

Limitations and pitfalls

Despite the fact that the different display modes enable an excellent demonstration of the fetal face there are a few situations that can cause problems [30]: 1. Fetal or probe movements during data acquisition lead to motion artifacts (Fig. 18), 2. surface rendering cannot be done in severe oligohydramnios, 3. overlying or adjacent structures interfere with surface rendering and must first be removed with the electronic scalpel, 4. arms or legs in front of the fetal face can cause shadowing artifacts defects because of the long bones, 5. setting the threshold too high or faulty manipulation of the electronic scalpel leads to iatrogenic structural defects and 6. the surface display of the fetal face in the early embryologic development (first trimester or beginning of the second trimester) does not show the typical human facial appearance as observable in the late second or in the third trimester and this should not be misinterpreted as a malformation of the fetal face.

Table 2 Assessment of the fetal face by 3D US in the second and third trimesters.

| 1. Anatomy (3-or-orthogonal-plane display/3D surface display/3D transparent [= maximum intensity] display) | sagittal view | – profile with forehead, nose, lips and chin – maxilla width ratio – mandible width |
| corona | – forehead with metopic (= frontal) suture – orbits with lenses (symmetry) – lips – palate (3D surface rendered image and transparent (= maximum intensity) image) – maxilla – mandible |
| transverse view | – orbits with lenses (symmetry) – palate transparent (= maximum intensity) image and 3D surface rendered image – maxilla – mandible |

2. Biometry

| sagittal view | – nasal bone – frontomaxillary facial (FMF) angle – inferior facial angle (IFA) |
| corona | – orbital diameter – inner orbital distance – outer orbital distance |
| transverse view | – orbital diameter – inner orbital distance – outer orbital distance – maxilla width – mandible width or jaw index |

3. Documentation

| – profile with nasal bone – corona | – profile with nasal bone – corona or transverse view with orbits – corona with lips – corona with palate |

Fig. 17 Three-orthogonal-plane of a fetus at 29 weeks of gestation with normal inferior facial angle (IFA) of 74°. The IFA is defined on a sagittal view by the crossing of two lines: 1. a line orthogonal to the vertical part of the forehead, drawn at the level of the synostosis of the nasal bones (reference line), 2. a line joining the tip of the mentum and the anterior border of the more protrusive lip (profile line). After Rotten et al. [28].
Conclusions

3D/4D ultrasound with its different display and volume manipulation possibilities offers a unique opportunity to demonstrate the normal and abnormal fetal face in detail. In cases with facial pathology this technique will help in appreciating the severity of the anomaly and in communicating of the defect with the neonatologist, the face surgeon and the parents. However, like in every imaging technology, it is necessary to know the limitations of 3D/4D scanning and to be aware of possible pitfalls.

References