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Original Article

Application research on three-dimensional ultrasonic skeletal imaging mode in detecting fetal upper jaw bone

Li-Peng Zheng, Li-Li Gong, Fang-Chun Guo, Hong-Bo Chang, Guang-Hua Liu

Department of Ultrasound, Linzi People's Hospital of Zibo, Shandong 255400, China

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Abstract: Objective: To detect three-dimensional (3D) ultrasound appearance of fetal normal and abnormal supermaxilla bone's anatomy using skeletal rendering mode, and to compare the success rate of 3D images in different gestational age groups. Methods: Using three-dimensional ultrasound skeletal rendering mode of voluson 730 and voluson E8 ultrasound systems, the fetal supermaxilla bones were reconstructed, the supermaxilla bones include two hundred and sixty-one cases with the range from 12 to 40 gestaional weeks that were normal supermaxilla proved by 2D ultrasound exam, three cases that were the specimens of fetal normal supermaxilla, and eight cases that were abnormal supermaxilla. The normal supermaxilla's imaging success rates of different gestational ages were contrasted. Results: The success rate of normal fetal supermaxilla bone's formation and structure with the 3D image was 97.9% during the gestation of 12~15^{+6} weeks, 96.0% of 16~21^{+6} weeks, 98.4% of 22~27^{+6} weeks, 68.6% of 28~35^{+6} weeks, 27.5% of 36~40 weeks. Through the X^2 test, there was no significant difference in the success rate of displaying among the gestation of 12~15^{+6} weeks, 16~21^{+6} weeks and 22~27^{+6} weeks. The success rate during the gestation of 36~40 weeks was the lowest among all the gestation. Big anatomic structures of fetal supermaxilla in 3D images can be shown, but detail cannot. The success rate of cleft palate with 3D image was 100% (8 cases). Conclusions: 3D ultrasound can supply more detailed and comprehensive information of fetal supermaxilla bone. The better fit examine weeks for obtaining 3D images are within 12~35^{+6} weeks, the best fit examine weeks are within 16~27^{+6} weeks. The function of 3D skeletal rendering mode image can display cleft palate clearly.

Keywords: 3D, skeletal rendering mode, ultrasonography, prenatal, fetus, supermaxilla bone

Introduction

Three-dimensional ultrasonic imaging technology allows rapidly establishing a volume database and reconstructing a solid and visual three-dimensional image for the region of interest [1]. In addition, the maximum transparent imaging mode can highlight the hyperechoic bone structure in fetuses. Therefore, this technology provides a good way to observe the development of fetal bone system [2, 3]. In 1995, Horst et al. described the advantages of three-dimensional ultrasonic transparent imaging mode in detecting fetal spine anomalies [4]. In this research, three-dimensional ultrasonic skeletal imaging mode, mainly the maximum transparent imaging technology was adopted for three-dimensional ultrasonic reconstruction for the structure of fetal upper jaw bone, the development of fetal upper jaw bone was studied by analyzing the three-dimensional volume data of upper jaw bone, and the optimal time for detecting fetal upper jaw bone with three-dimensional ultrasonic skeletal imaging mode, and also the feasibility and correctness of diagnosis about fetal upper jaw bone malformation were discussed by comparing the success rates of imaging in different periods of pregnancy.

Data and methods

Subjects

261 pregnant women were randomly selected from those who received fetus routine examination in the outpatient department of our hospital from May 2010 to December 2010, and three-dimensional images of fetal upper jaw bone were collected with consents of these pregnant women. With an average age of (28.4±4.2), they were 20-41 years old and

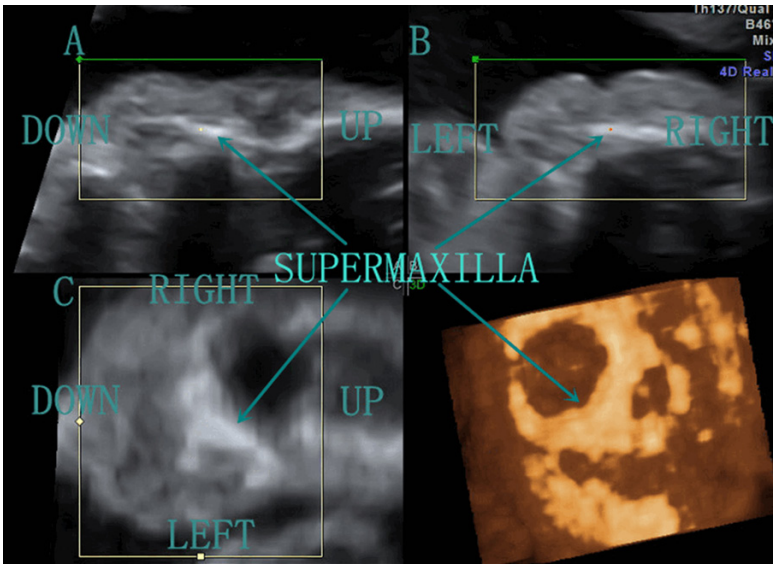

Figure 1. Facies lateralis of upper jaw bone displayed in three-dimensional ultrasonic skeletal imaging in 24 gestational weeks. In this figure, the initial interface of probe is sagittal section, and the fetus is in the cephalic position. X, Y, and Z axes are adjusted properly and image is enlarged to put the middle point in the high echo of upper jaw bone. The specific location is shown in the figure.

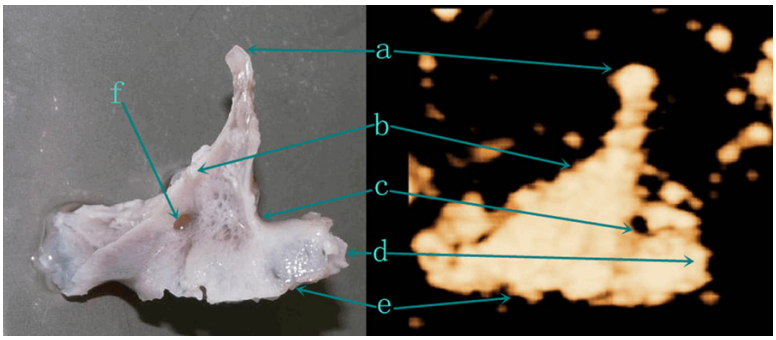

Figure 2. Comparison between actual specimen of facies lateralis of left upper jaw bone of fetus in 30 gestational weeks and three-dimensional ultrasonic imaging - a: frontal gibbosity, b: infraorbital margin, c: nasal incisura, d: anterior nasal spine, e: alveolar process, f: infraorbital foramen.

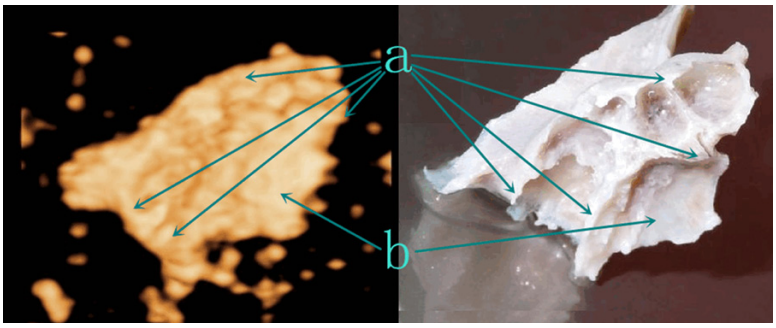

Figure 3. Comparison between actual specimen of inferior surface of left upper jaw bone of fetus in 30 gestational weeks and three-dimensional ultrasonic imaging -a: alveolar process, b: hard palate.

12-40 weeks in gestation age. All the subjects had no complication of abnormal pregnancy.

There were three specimens of fetuses by induced labor due to non-facial malformation at the gestation age of 21~30 weeks.

Eight fetuses with cleft lip and palate by two-dimensional ultrasonic inspection at the gestation age of 20~34 weeks were proved after labor induction or parturition by reconstructing fetal upper jaw bone with three-dimensional ultrasound.

Instruments and methods

GE Voluson 730 and Voluson E8 three-dimensional ultrasonic imaging systems were applied with a three-dimensional volume probe of transabdominal convex array and with a frequency of 4~8 MHz.

The pregnant women were asked to expose the abdomen in a supine position, or in a lateral position if necessary.

Firstly, routine two-dimensional ultrasonic inspection was conducted towards the fetal face to observe his/her upper jaw bone. It was observed whether there was umbilical cord or limb in the amnionic fluid before the face on the condition of avoiding limb bone as much as possible.

The probe was put on the abdominal wall in front of fetal face, and then three-dimensional skeletal imaging mode was started to obtain the three-dimensional volume data of fetal face. The

Table 1. Comparison of success rates for three-dimensional ultrasonic skeletal imaging of upper jaw bones 261 fetuses in different gestational weeks

Gestational weeks	Cases	Successful cases	Failure cases	Success rate (%)
12~15^{+6} weeks	48	47	1	97.9
16~21^{+6} weeks	50	48	2	96.0
22~27^{+6} weeks	61	60	1	98.4
28~35^{+6} weeks	51	35	16	68.6
36~40 weeks	51	14	37	27.5
Total	261	204	57	78.2

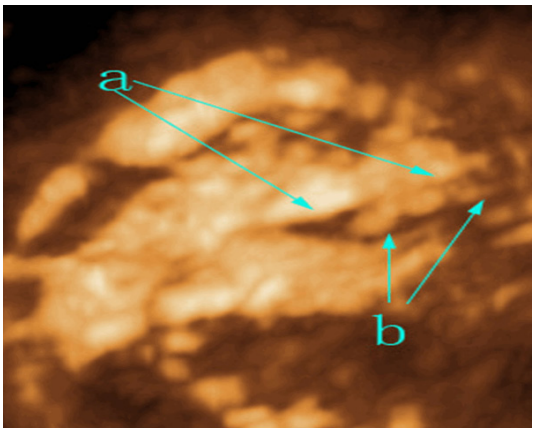

Figure 4. Three-dimensional imaging display of upper jaw bone of fetus in 17 gestational weeks -a: lateral border of alveolar process, b: medial border of alveolar process.

probe was put in the right ahead of upper jaw bone as much as possible during the three-dimensional scanning. In general, 3 images were collected with a total period of less than 3 min. The obtained three-dimensional volume data were stored in the diagnostic unit.

X, Y, and Z axes were rotated to obtain the three-dimensional image of fetal upper jaw bone (**Figure 1**) which shows the solid structure of fetal upper jaw bone. On the image, the superior border, inferior border and medial border of the upper jaw bone were observed and also anterior nasal spine and nasal incisura for fetuses after 16 gestational weeks.

Fetal upper jaw bone specimen was obtained by anatomy, and three-dimensional ultrasonic imaging was conducted towards the specimen so as to observe all the bony landmarks. Then, comparison was conducted (**Figures 2** and **3**).

Statistical analysis

SPSS 13.0 statistical software was applied. By X^2 split-run, multiple comparisons were conducted for the success rates of inspection in different periods of pregnancy and also among different groups.

Result

I. Among 261 subjects, 204 three-dimensional images of fetal upper jaw bone were obtained successfully by three-dimensional ultrasonic skeletal imaging mode. Different display success rates of fetal upper jaw bone were found in different gestational weeks. Please refer to **Table 1** for specific data.

Success rates of three-dimensional ultrasonic imaging of upper jaw bone in different gestational weeks were compared by X^2 test. Based on the comparison, the success rates in different gestational weeks were different (X^2=114.4, P<0.001). According to partition test with the R*C table, the differences in the success rates of 12~15^{+6} weeks, 16~21^{+6} weeks, and 22~27^{+6} weeks were not significant statistically (X^2=0.68, P=0.71), so it can be considered that the success rates of three-dimensional imaging for fetal upper jaw bone in such three inspection periods have no difference. The differences in those of 28~35^{+6} weeks and 36~40 weeks all have statistical significance when compared with those of other groups (P<0.001), that means, the success rates of three-dimensional imaging for fetal upper jaw bone in 12~27^{+6} weeks are relatively higher, while those in 36 to 40 weeks were relatively lower.

II. The image can show the major structure of fetal upper jaw bone, but poorly in details. Frontal gibbosity, nasal incisura, anterior nasal spine, alveolar process, and infraorbital border were shown clearly, while relatively small structures and joints with other bones not, including infraorbital foramen, infratemporal surface, and zygomatic process (**Figures 2-4**).

III. Ultrasonogram expression of three-dimensional ultrasonic skeletal imaging. Only a right triangle which seems to be laid flatwise is shown in the three-dimensional image for upper jaw bone of fetus in 12 to 15 gestational weeks (**Figure 5**). All important bony landmarks are unclear. The nasal incisura appear since the 15th gestational week. Nasal incisura and

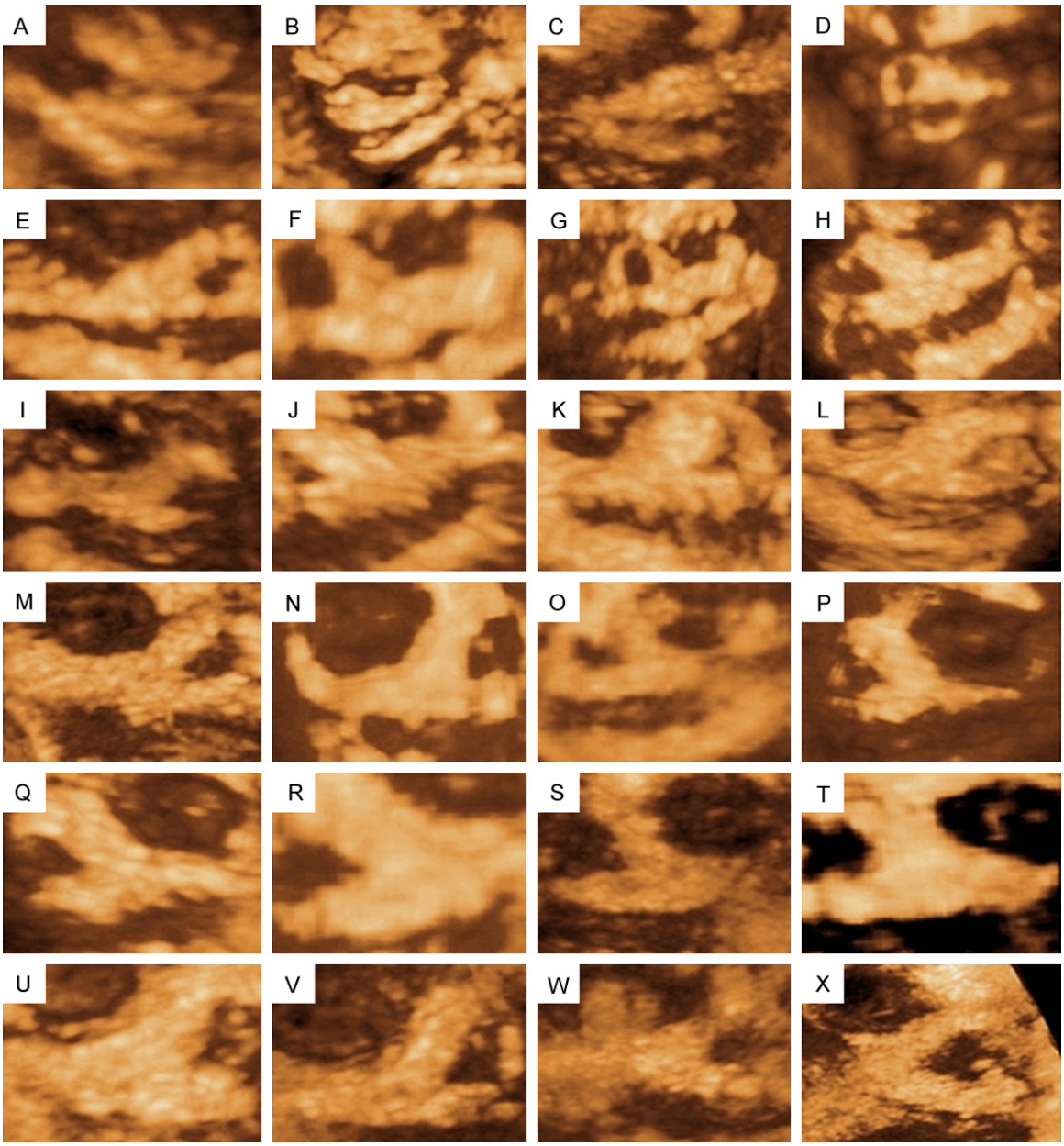

Figure 5. Three-dimensional ultrasonic display of fetal upper jaw bone - A: 12 gestational weeks. B: 13 gestational weeks. C: 14 gestational weeks. D: 15 gestational weeks. E: the beginning of 16 gestational weeks. F: the middle of 16 gestational weeks. G: 17 gestational weeks. H: 18 gestational weeks, I: 19 gestational weeks. J: 20 gestational weeks. K: 21 gestational weeks. L: 22 gestational weeks. M: 23 gestational weeks. N: 24 gestational weeks. O: 25 gestational weeks. P: 26 gestational weeks. Q: 27 gestational weeks. R: 28 gestational weeks. S: 29 gestational weeks. T: 30 gestational weeks. U: 32 gestational weeks. V: 33 gestational weeks. W: 34 gestational weeks. X: 35 gestational weeks. The figure shows that the nasal incisura appears since the 15th gestational week, and nasal incisura and anterior nasal spine can be clearly shown in the 16th gestational week.

anterior nasal spine can be clearly shown and the fetal upper jaw bone starts to be similar to that of adults from the 16th week. Later the image of upper jaw bone changes with the gestation age in the aspects of marginal texture and clearness degree of important bony landmarks, but the change is not great (**Figure 5**). After 36 gestational weeks, it is difficult to obtain relatively complete three-dimensional image of fetal upper jaw bone (**Figure 6**).

IV. In case there is cleft palate malformation in fetal upper jaw bone, the cleft gap of upper jaw bone would be shown clearly in three-dimen-

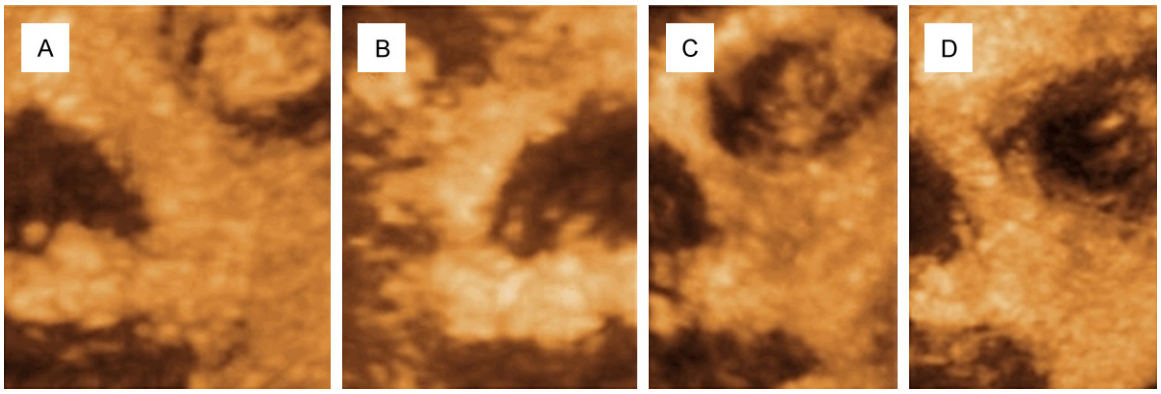

Figure 6. Three-dimensional ultrasonic display of fetal upper jaw bone. A: 36 gestational weeks. B: 38 gestational weeks. C: 39 gestational weeks. D: 40 gestational weeks.

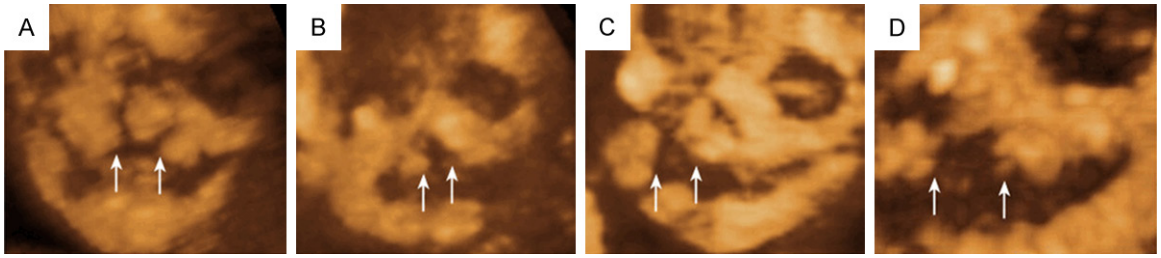

Figure 7. Three-dimensional imaging of upper jaw bone of fetus with cleft palate malformation. A: 25 gestational weeks (both sides). B: 26 gestational weeks (single side). C: 27 gestational weeks (single side). D: 20 gestational weeks (single side). The arrow points to the osteal border of upper jaw cleft.

sional ultrasonic skeletal imaging. In addition, discontinuous echo image of upper jaw bone from alveolar process to nasal incisura, and that of hard palate by rotating X axel would be observed (**Figure 7**).

Discussion

The earliest ossification and the latest ossification of the upper jaw bone in the same position differ by one week for different fetuses [5]. Upper jaw, frontal gibbosity, and zygomatic process have been ossified before the 12th gestational week, and anterior nasal spine and nasal incisura in the 16th gestational week at the earliest. Three-dimensional ultrasonic skeletal imaging can show the solid image of triangle upper jaw bone after 12 gestational weeks, and anterior nasal spine and nasal incisura can be clearly shown in the three-dimensional image of upper jaw at the 16th gestational week.

Inside the soft tissue, fetal upper jaw bone is irregular in its shape, so it should be scanned repeatedly during two-dimensional ultrasonic examination, and a solid model should be established in doctor's mind. Without objectively constructing a solid shape, subjective judgment of whether the shape is normal is difficult to satisfy the demands of clinical diagnosis, so repeated examination should be carried out in clinic consultation. Three-dimensional ultrasonic skeletal imaging can: (1) show the general solid structure of fetal upper jaw bone and clearly show all bony landmarks because of anatomic characteristics; (2) be stored and reconstructed without repeated examination; (3) rotate all axial sections to graphically show the curvature and angle of bone.

The display success rates of fetal upper jaw bone has great difference with imaging rates of static three-dimensional ultrasonic imaging of 64 fetal skulls in different gestational weeks made by Xu Jianping, et al. [6], among which the difference of 36~40 gestational weeks is the largest (Xu Jianping, et al. conducted study on 5 fetuses in 37~40 gestational weeks, and static three-dimensional imaging was successful in 3 fetuses with a success rate of 60.0%). The author believes that the reasons are as follows: (1) The standards for imaging success are

much stricter in this study; (2) In late pregnancy, the echo intensity of fetal skin surface is approximate to that of fetal upper jaw bone. The anterior soft tissue of upper jaw bone thickens, so the echo is higher and ultrasonic energy decrement increases; (3) The fetal body volume is large, while the external condition like amniotic fluid is poor.

The display success rate of upper jaw bone of fetuses in 12~27^{+6} gestational weeks is higher, and the solid images are clearer. In the 16th gestational week, the significant bony landmarks show ossification. Therefore, 16~27^{+6} weeks is the most ideal period for three-dimensional examination of fetal upper jaw bone.

The morbidity of cleft lip and palate is high [7-10] and associated with inheritance, environment, and drug factor [11-18]. The diagnosis of fetal cleft palate malformation is always difficult in ultrasonic diagnosis [19]. Two-dimensional ultrasonic diagnosis requires observation of palate echo, but palate is at the top of oral cavity with tissues in the front and both sides, so the display is limited. Li Shengli et al. [20] and Chang Hongbo et al. [21] all found the method to display hard palate. According to the study by Zhang Xiaohang et al. [22], the accuracy to diagnose fetal cleft lip and palate by two-dimensional ultrasound was only 69.57%. Three-dimensional ultrasonic diagnosis for fetal facial malformation [23-27] has appeared, so the three-dimensional ultrasonic skeletal imaging mode simplifies the requirements of the techniques in two-dimensional ultrasonic examination, shortens the scanning time, and can clearly show the cleft of upper jaw bone. The author conducted three-dimensional bone reconstruction for fetal upper jaw of 8 fetuses with cleft palate malformation with a display success rate of 100% which is almost consistent with the coincidence rate of 95.65% for cleft palate diagnosis in the study by Zhang Xiaohang et al. [9].

Disclosure of conflict of interest

None.

Address correspondence to: Guang-Hua Liu, Department of Ultrasound, Linzi People's Hospital of Zibo, Shandong 255400, China. Tel: +86053371-62056; Fax: +8605337180469; E-mail: guanghualiudoc@sina.com

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