

Enhancing diagnostic accuracy of fetal chromosomal abnormalities using automated ultrasound image processing of the nasal bone

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ABSTRACT

This paper presents an algorithm for the automatic processing of ultrasound images of the fetal head, aimed at detecting and measuring the nasal bone. Ultrasound examination during the first trimester (11–14 weeks) plays a critical role in assessing the risk of chromosomal abnormalities. However, visualizing the nasal bone can be challenging due to its small size and variability in image quality across ultrasound devices. The proposed algorithm combines Gaussian and median filtering for noise suppression and employs an improved Otsu segmentation method to enhance reliability. The system was validated using phantom-generated images as references, achieving a measurement accuracy within one pixel.

Keywords: diagnostics, ultrasound imaging, chromosomal anomaly, nasal bone, Gaussian filtering and median filtering, Otsu's method, measurement

1. INTRODUCTION

Timely diagnosis of chromosomal abnormalities is one of the primary objectives of antenatal care. Ultrasound screening during the first trimester (11–14 weeks), in conjunction with biochemical markers, is considered highly effective for early detection. The standard diagnostic approach estimates chromosomal anomaly risk based on factors such as maternal age and history, gestational age, ultrasound-measured nuchal translucency thickness, nasal bone evaluation, and serum levels of free β -hCG and pregnancy-associated plasma protein A. Absence or hypoplasia of the nasal bone, especially when observed alongside increased nuchal translucency, is a strong indicator of trisomy 21 (Down syndrome). Notably, nasal bone abnormalities are seldom found in fetuses with a normal karyotype, highlighting the diagnostic importance of nasal bone measurement. In healthy fetal development, the nasal bone typically ranges in length from 2 to 4.2 mm^{1,2}.

2. DEVELOPMENT OF THE ULTRASOUND IMAGE PROCESSING ALGORITHM

Ultrasound imaging is a widely used screening method. For nasal bone evaluation, a mid-sagittal view is recommended, with the image magnified to include the echogenic nasal tip and rectangular hard palate anteriorly. The translucent diencephalon and nuchal membrane can be visualized posteriorly. The nasal bone lies beneath the facial skin line and should appear more echogenic than the skin on the nose tip. If the nasal bone is less echogenic, it is classified as hypoplastic or absent³. Due to the bone's small size, reliable visualization and measurement can be challenging. Manual placement of measurement markers can lead to significant errors, up to 4–5 pixels, potentially resulting in inaccurate diagnoses.

One of the most important screening methods is ultrasound (US). The nasal bone is assessed in a mid-sagittal section with a magnification of the ultrasound image, which includes the echogenic tip of the nose and the rectangular shape of the palate anteriorly. Posteriorly, the translucent medulla and the collar membrane can be identified. The nasal bone lies below the echogenic line of the facial skin and should be more echogenic than the skin on the tip and dorsum of the nose.

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If the nasal bone is less echogenic than the skin over it, it is considered hypoplastic or absent^{3,4,5}.

Ultrasonic determination and measurement of the nasal bone can be problematic, since visualization of the object, given its small size, can be difficult. In addition, there may be errors by the physician in accurately determining the dimensions of the nasal bone, since, in this case, the dimensions are determined by applying markers of the beginning and end of the bone on the ultrasound image. In this case, the absolute error in determining the coordinates of the markers can reach several pixels, which, in some cases, can lead to an incorrect diagnosis^{6,7,8}.

Fig. 1a shows an ultrasound image of the fetal head of the child, as well as markers applied in the nasal bone area. It was subsequently found that the absolute error in determining the dimensions of the nasal bone using markers applied by the doctor was 4-5 pixels. Figure 1 illustrates an original ultrasound image with nasal bone markers placed manually^{9,10,11}. Figure 2 shows preprocessing results, indicating that incorrect marker placement may lead to inaccurate dimension estimation, and therefore to an erroneous diagnosis.



Figure 1. Ultrasound images with nasal bone markers exposed.

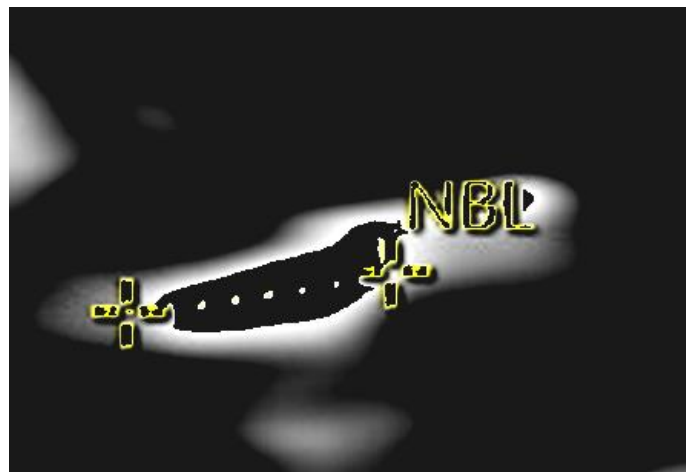


Figure 2. Ultrasound image of the nasal bone and marker positions

To increase the reliability of identifying chromosomal anomalies of the fetus by the size of the nasal bone, an algorithm for processing ultrasound images is proposed in the work. Figure 3 outlines the algorithm's stages, including filtering, contrast adjustment, segmentation, and measurement¹²⁻¹⁵. The algorithm uses Gaussian filtering to smooth the image and reduce high-frequency noise, and a median filter to remove impulse noise while preserving edges. These steps address inconsistencies in image quality from various ultrasound machines¹⁶⁻¹⁸. Following filtering, linear contrast enhancement

is applied. This is essential for improving visualization of anatomical boundaries. Next, an improved version of Otsu's method is used for threshold segmentation, which adapts to local intensity variations for better accuracy in heterogeneous regions^{4,5,6}. The result is an automatic and highly precise measurement of nasal bone length¹⁹.

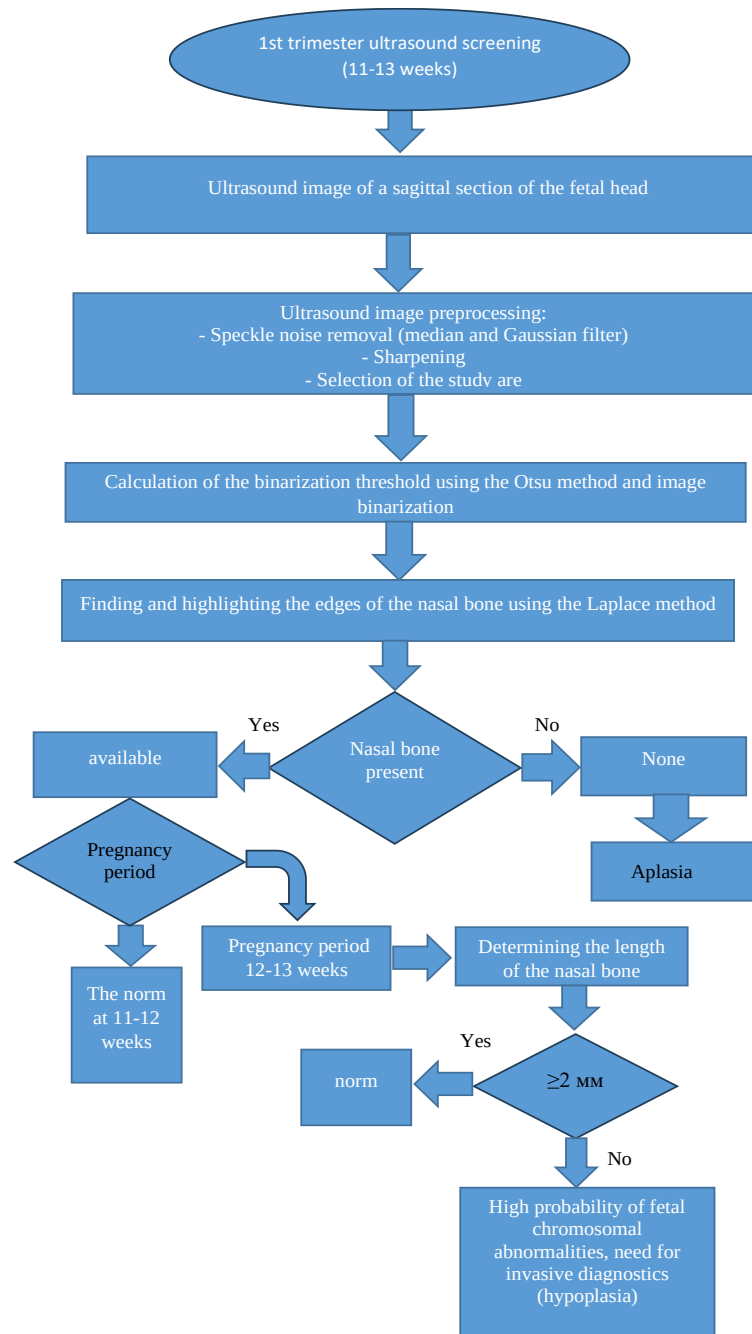


Figure 3. Algorithm for secondary processing of ultrasound images and determination of nasal bone dimensions

Figure 4 displays the original ultrasound image of the fetal head. Figure 5a shows the binarized image, 5b its histogram, and 5c an oscillogram of the nasal bone.



Figure 4. Ultrasound image of a baby's head in the womb.

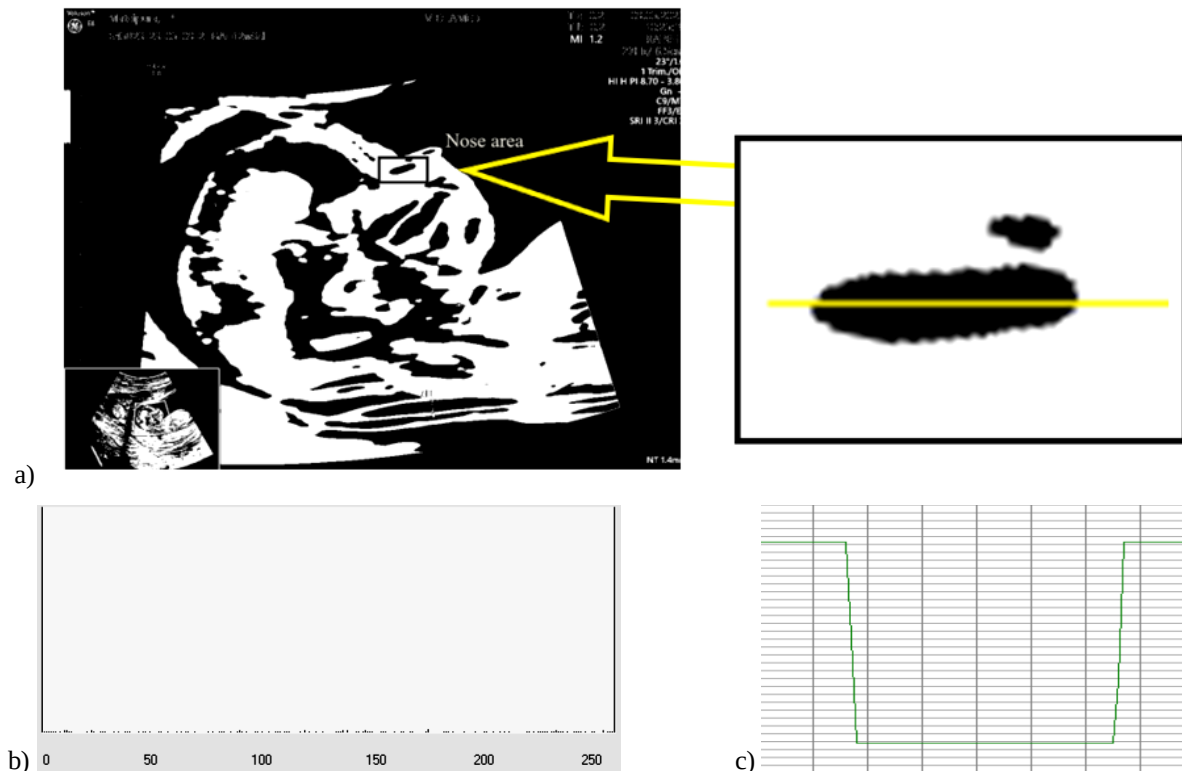


Figure 5. Image of the fetal head as a result of computer processing and the results obtained: a) binarized image of the fetal head and the selected image of the nasal bone; b) histogram of the binarized image; c) oscillogram of the nasal bone

Segmentation produces a contour image (Figure 6) that highlights regions of interest such as the diencephalon and nuchal space, facilitating further clinical evaluation.

To validate the algorithm, ultrasound images of a phantom fetus (SPACE FAN-ST model) were analyzed. This training model replicates fetal anatomy and allows for realistic imaging using 2D or 3D sensors. The evaluation demonstrated that the algorithm achieved dimensional accuracy within 1 pixel.



Figure 6. Contour image of the fetal head

3. CONCLUSION

Ultrasound image processing plays a crucial role in medical diagnostics. This study introduces an automated processing algorithm that significantly improves the reliability of nasal bone measurements—one of the key markers in fetal chromosomal anomaly screening. The algorithm is efficient, requires minimal computational resources, and demonstrated a measurement error of no more than 1 pixel. These findings suggest its strong potential for integration into routine ultrasound diagnostics.

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