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Technical Note
Cleft Anomalies

Three-dimensional printed haptic model from a prenatal surface-rendered oropalatal sonographic view: a new tool in the surgical planning of cleft lip/palate

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Abstract. Three-dimensional (3D) ultrasound has significantly improved prenatal screening and perinatal care in the area of cleft lip/palate and other deformities, providing essential preoperative information to the surgical team. However, current 3D reconstruction modalities are limited primarily to display on a two-dimensional surface. In contrast, a 3D printed haptic model allows both the surgeon and the parents to develop a better understanding of the anatomy and the surgical procedure through the ability to interact directly with the printed model. The production of a 3D printed haptic model of cleft lip and palate obtained from a surface-rendered oropalatal sonographic view is presented here. The development of this 3D printed haptic model will allow the surgical team to perform preoperative planning with a highly accurate medical model, and it therefore represents a new tool in the management of cleft lip/palate. It also provides better prenatal information for the parents.

Key words: ultrasonography; cleft lip/palate; printing; three-dimensional; craniofacial abnormalities.

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Recent advances in prenatal ultrasound have made the in utero diagnosis of cleft lip and palate and associated deformities possible[1]. Three-dimensional (3D) ultrasound has significantly improved prenatal screening and perinatal care in the area of cleft lip/palate and other deformities, providing essential preoperative information to the surgical team through visualization of the dental and associated structures[2,3].

Surface rendering of the foetal face has become an essential prenatal tool, allowing better planning of future surgical procedures. These surface-rendered representations offer the possibility of easier communication between members of the surgical team. They also yield precise information for parents and provide them with a representation of the defect affecting their unborn child[4,5].

However, current 3D reconstruction modalities are limited primarily to display on a two-dimensional (2D) surface. In contrast, a 3D printed haptic model allows both the surgeon and the parents to develop a better understanding of the anatomy and the surgical procedure through the ability to interact directly with the printed model.

The cost and size of 3D printers have decreased rapidly over the past decade, in parallel with the expiration of key 3D printing patents, allowing them to be used more widely in medical practice. Data for 3D printed medical models can be obtained from computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound using DICOM software (Data Imaging and Communications in Medicine). Data images are processed using segmentation and mesh generation tools and converted to standard tessellation language (STL) files for printing. Currently, fused deposition modelling (FDM) is the most commonly used and the most affordable consumer 3D printing technology available. Acrylonitrile-butadiene-styrene (ABS) and polylactic acid (PLA) are the plastics most frequently used as raw materials in FDM printers.

The production of an ABS model of a foetus with a cleft lip at 24 weeks of gestation, obtained with a low-cost 3D FDM printer from a surface-rendered oropalatal (SROP) sonographic view, is described herein.

Technique

SROP sonographic view acquisition

The examination was performed using a Voluson E8 ultrasound machine fitted with 3D RAB 4–8 or RM6C abdominal mechanical transducers (GE Healthcare, Velizy, France).

As described previously[4,5], the acquisition protocol involves an anterior coronal view used to image the upper lip, an axial view to image the alveolar ridge, and a mid-sagittal view to examine the middle of the upper lip using 2D ultrasonography. A surface-rendered coronal view of the face using 3D ultrasonography is usually employed to complete this screening protocol. The analysis protocol is based on multiplanar reconstructions in the three traditional orthogonal planes and tomographic reconstructions. It is completed by the reconstruction of the SROP view (Fig. 1).

To minimize shadowing from the malar bones and allow visualization of the posterior limit of the bony palate, the foetal head must be in a slightly deflected position. Additionally, the foetal face must be in an anterior position facing the transducer. The mouth should be open or half-open, and the tongue should be separated from the palate. The benefit is good contrast due to the presence of amniotic fluid in the oral cavity. The axis of the transducer is set in a strict midsagittal plane, and the speed of the mechanical sweep is set for high quality (slow sweep).

A frontal view of the palate is obtained. The view is oriented in an oblique direction, directed upward, cephalic to caudal. The virtual lighting (HD Live) is focused on the frontal view of the palate. Finally, the mandible is removed using the electronic scalpel.

From ultrasound to the 3D printed haptic model

The Voluson E8 ultrasound machine does not currently allow the export of files in DICOM format. After conversion of the source file into STL format with in-house software, Netfabb software (Autodesk San Rafael, California, United States) was used to repair the STL file before 3D printing.

In the case presented here, 3D printing was performed with the low-cost 3D printer UPplus2 (Beijing Tiertime Technology Co. Ltd, Beijing, China). The UPplus2 3D printer is a rapid prototyping machine based on a fused deposition modelling technique that uses ABS as a raw material. UP is the software provided with the 3D printer. Figure 2 is a screenshot from the UP software that shows the STL file before 3D printing. The 3D models were created layer by layer with 0.15-mm thickness, which is the minimum achievable thickness for that particular printer. The ABS model created, which weighed close to 71.6 g, took 6 h 52 min to print in fine quality and with a lightweight filling modality (Fig. 3). ABS was chosen as the material for use, as it seems to provide printed models with good definition. Plastic ABS models printed by the low-cost 3D UPplus2 printer have been shown to provide dimensional accuracy that is comparable to other well-established high-cost professional rapid prototyping technologies[6].

Discussion

To produce this 3D-printed haptic model, software was required to convert the source file of the machine to an STL file. Indeed, the Voluson E8 ultrasound machine does not allow for export in DICOM format. However, it is expected that foetal ultrasound machines will soon be able to export DICOM files for use in producing a 3D medical model, or be linked directly to a 3D printer. In addition, the routine application of this tool in the management of cleft lip/palate or other malformations requires that DICOM files can be obtained on foetal ultrasound machines, thus avoiding the use of CT[7] and MRI[8].

The 3D printed haptic model has several advantages over the 3D reconstruction supplied by the ultrasound machine. First, it serves to provide a realistic view of the printed object, providing much more information than a picture on a computer screen. It can also be manipulated and annotated. This is important for surgical planning, making pre-surgical drawings possible. At the 100% scale, it also allows for accurate measurements.

Fig. 1. Reconstruction of the surface-rendered oropalatal (SROP) view of a foetus with cleft lip and palate at 24 weeks of gestation.