Original Investigation

Creation and Validation of a Simulator for Neonatal Brain Ultrasonography: A Pilot Study

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Rationale and Objectives: Historically, skills training in performing brain ultrasonography has been limited to hours of scanning infants for lack of adequate synthetic models or alternatives. The aim of this study was to create a simulator and determine its utility as an educational tool in teaching the skills that can be used in performing brain ultrasonography on infants.

Materials and Methods: A brain ultrasonography simulator was created using a combination of multi-modality imaging, three-dimensional printing, material and acoustic engineering, and sculpting and molding. Radiology residents participated prior to their pediatric rotation. The study included (1) an initial questionnaire and resident creation of three coronal images using the simulator; (2) brain ultrasonography lecture; (3) hands-on simulator practice; and (4) a follow-up questionnaire and re-creation of the same three coronal images on the simulator. A blinded radiologist scored the quality of the pre- and post-training images using metrics including symmetry of the images and inclusion of predetermined landmarks. Wilcoxon rank-sum test was used to compare pre- and post-training questionnaire rankings and image quality scores.

Results: Ten residents participated in the study. Analysis of pre- and post-training rankings showed improvements in technical knowledge and confidence, and reduction in anxiety in performing brain ultrasonography. Objective measures of image quality likewise improved. Mean reported value score for simulator training was high across participants who reported perceived improvements in scanning skills and enjoyment from simulator use, with interest in additional practice on the simulator and recommendations for its use.

Conclusions: This pilot study supports the use of a simulator in teaching radiology residents the skills that can be used to perform brain ultrasonography.

Key Words: Brain ultrasonography; simulation training; ultrasound phantom; resident education; neurosonography.

INTRODUCTION

Brain ultrasonography (1–5) is a study frequently performed on neonates. In 2015 alone, 1459 such studies were performed at our tertiary-care children's hospital, with the most common indications being a drop in hematocrit, enlarging anterior fontanelle, prematurity, pre- and peri-extracorporeal membrane oxygenation evaluations, and abnormal neurologic examination. Most of these studies were requested on an emergent basis, and they often play an essential role in guiding management (6–8). Given the ubiquity, time sensitivity, and importance of this examination, brain ultrasonography is a technique radiology trainees are expected to learn during residency training (9,10). However, most graduating residents are not proficient in performing this type of examination. The lack of supervision, structure, and assessment of competency during training had been cited as potential causes of this inadequacy (11). Additional pediatric radiology fellowship training is often required to attain proficiency.

Historically, brain ultrasonography is taught through a "master-apprentice" educational model in which an experienced provider performs the examination as the trainee observes. The trainee then attempts to perform the test under close supervision, slowly gaining the necessary psychomotor skills required to successfully perform the task (12). This approach has several drawbacks, including longer imaging times, patient discomfort/inconvenience/medical fragility, limited accessibility of patients, and risk of a suboptimal examination. In an increasingly demanding and time-constrained health-care environment, opportunities for consistent trainee

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supervision and effective learning are becoming fewer and far between, further compromising this traditional master-apprentice educational model. Other medical fields that require skills training are faced with similar challenges and have turned to simulation training with varying degrees of success (13–16).

Adapted from high stakes industries such as air travel and nuclear power, medical simulation centers on "on-demand" and relevant deliberative practice opportunities with feedback, all without threat or inconvenience to real patients. The educational experience is hands-on and practical, and allows for repetition. Through simulation, trainees develop the required hand-eye coordination and cognitive experience necessary to perform examinations and interventions on actual patients. Although simulation-based skills training has been shown to be an effective teaching tool in multiple disciplines (17), to our knowledge, there is no existing simulator model for teaching the skills needed to perform brain ultrasonography on infants. To this end, this study describes the creation and validation of a synthetic neonatal brain trainer as an educational tool in teaching the skills that can be used to perform brain ultrasonography.

MATERIALS AND METHODS

This study was reviewed by the institutional review board. Informed consent was waived.

Construction of Simulator Model

An infant brain simulator model (Fig 1) was assembled from three main components—brain phantom, plastic skull, and skin cover—at a cost of approximately $2000, including research and development, multiple iterations, and prototyping. Once assembled, the simulator is usable for many days at room temperature and may be preserved indefinitely if kept frozen. Two static images during real-time scanning of this simulator model are shown in Figure 2.

Brain Phantom

To ensure anatomic fidelity of a first-generation trainer, the geometry of the brain phantom was derived from a 3-month-old normal infant's brain magnetic resonance imaging. A 3-month-old infant was chosen (instead of a neonate) as the brain's sulcal pattern in this age group allows for a more accurate segmentation (ie, anatomic partitioning and delineation). This infant's brain parenchyma was semi-automatically segmented by intensity thresholding (by choosing an intensity value as a threshold in determining the partitioning), followed by hand refinement or manual segmentation (by an expert operator with strong background knowledge of the human brain anatomy). The segmentation was exported as a stereo lithography (STL) file, and then printed on an acrylonitrile butadiene styrene (ABS) three-dimensional (3D) printer (Stratasys, Ltd., Eden Prairie, MN). A silicon negative-mold was created from this 3D print. Polyvinyl alcohol (PVA) cryogel was cast in this silicon negative-mold to create the brain parenchyma phantom. PVA cryogel was chosen because it had been shown to be an effective tissue-mimicking material for ultrasound imaging (18). Empirically, we found that a concentration of 6% by weight of PVA dissolved in pure water best mimicked the ultrasound appearance of the brain parenchyma. The ventricles were preserved in this casting process by strategically embedding positive ventricular molds within the PVA cryogel. The solidification and polymerization of the

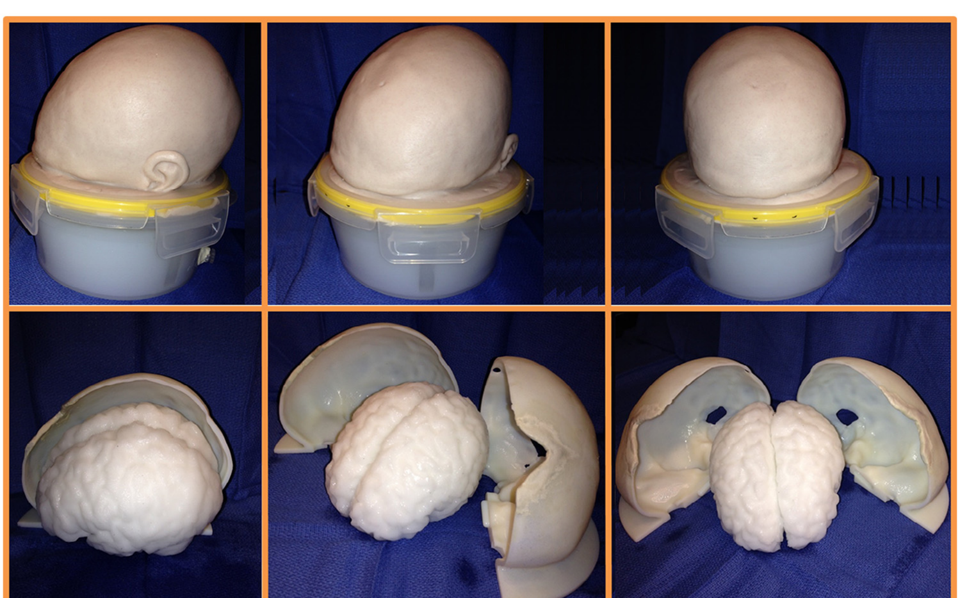

Figure 1. Brain ultrasonography simulator model. Top row shows the simulator model as viewed from different angles. Bottom row shows the corresponding appearance of the simulator model with the overlying skin cover removed and the plastic skull split in the sagittal plane for better visualization of the underlying brain phantom.