Automated Deep Learning Segmentation of Neonatal Cerebral Lateral Ventricles from Three-Dimensional Ultrasound Images

Zachary Szentimrey[a], Sandrine de Ribaupierre[b], Aaron Fenster[c], Eranga Ukwatta[a]

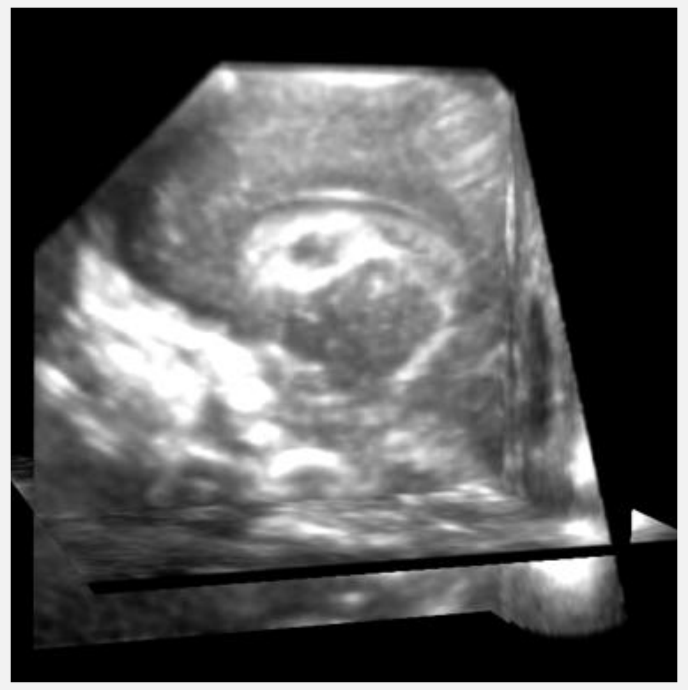
[a]School of Engineering, University of Guelph; [b]Department of Clinical Neurological Sciences, Schulich School of Medicine and Dentistry, University of Western Ontario; [c]Robarts Research Institute, University of Western Ontario

ABSTRACT

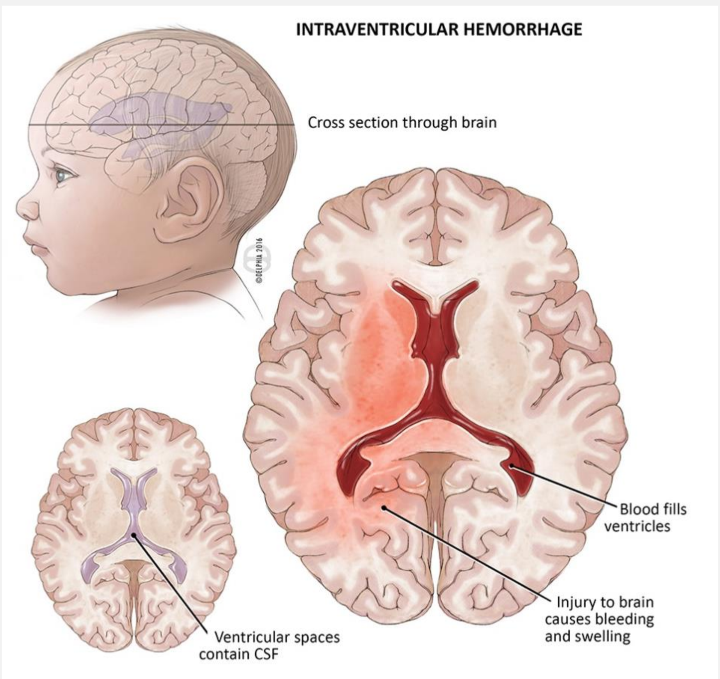
Neonates are susceptible to intraventricular hemorrhaging (IVH) in their cerebral lateral ventricles. This bleeding can cause major neurological harm so it is crucial to diagnose and treat IVH early. 3D ultrasound (US) provides a method of observing the ventricles safely and accurately. We developed a fast and fully automated segmentation algorithm using deep learning for 3D US images that yielded better or comparable results to traditional methods

PURPOSE & OBJECTIVES

The goal with our research is to provide a fast segmentation method that is fully automated and performs well when compared to previous non-deep learning methods. We aim to achieve this by implementing the ensemble model and pipeline shown after. The ensemble network consists of three 3D U-Net variant models, each highlighting certain aspects of the ventricles. In order to compare model performance, we use the three metrics explained in the Results section.



Example 3D Ultrasound Image



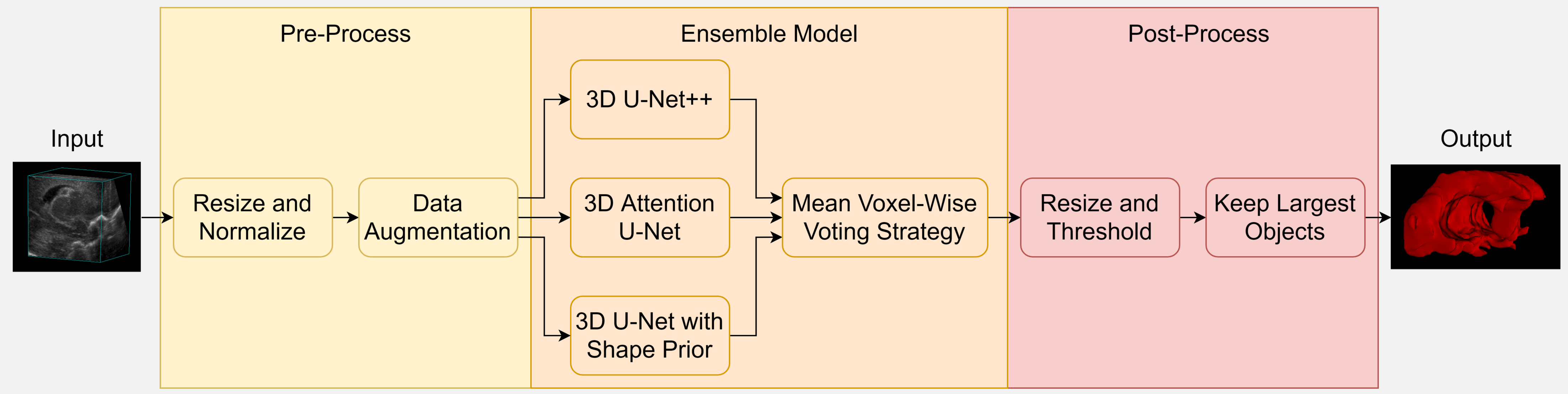
IVH in Neonates

E. Digitale, Stanford Children's Health, https://www.stanfordchildrens.org/en/service/neonatology/prenatal-steroids-reduce-preemies-risk-for-brain-bleeding

BACKGROUND

- IVH affects 20-30% of very low birth weight infants (<1500g). IVH can be described as a bleed located inside the cerebral lateral ventricles. IVH can lead to post-hemorrhagic ventricle dilatation (PVHD) which is an enlargement of the cerebral ventricles. As the ventricles increase in size, the intracranial pressure increases leading to an abnormal enlargement of the head for patients.
- Due to the speed at which IVH progresses and potential for neurological degradation, it becomes important to identify and treat patients who are affected as soon as possible. There are multiple ways of imaging neonatal cerebral ventricles including 2D US and MRI but they have many drawbacks including high user variability and high cost when compared to 3D US.

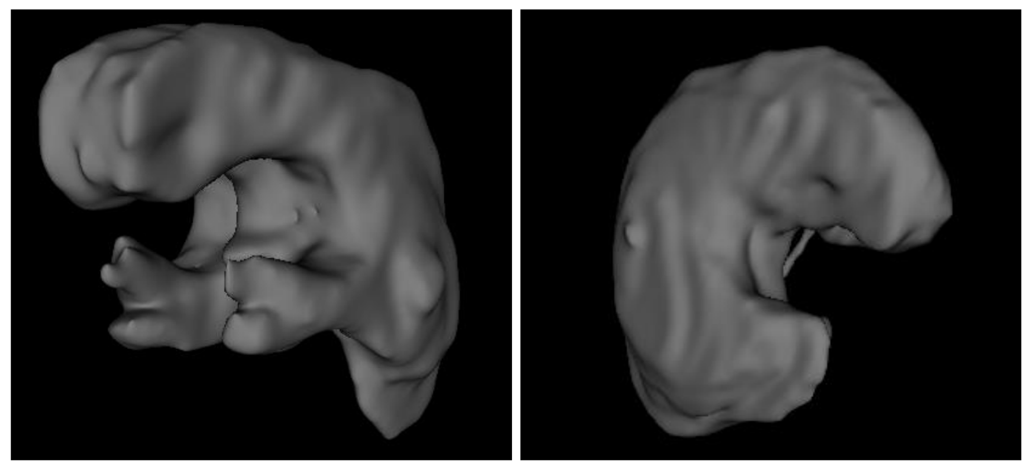
Segmentation Pipeline



METHODS

Data

In total, 190 images were used. 103 images contained only one lateral ventricle and 87 contained both lateral ventricles. When performing the experiments, the one and two ventricle images were split and each tested on separately with their own results. Dataset consisted of 30 patients with varying degrees of IVH and images used had the same patient scanned over multiple days.



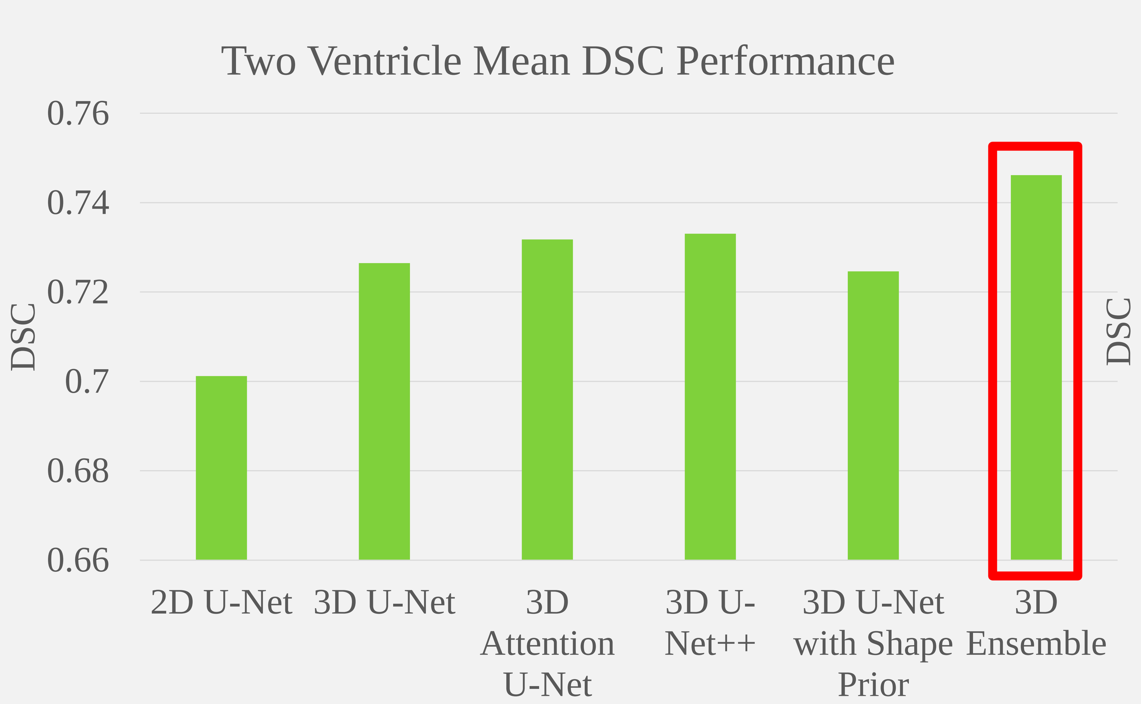
Two Ventricles One Ventricle

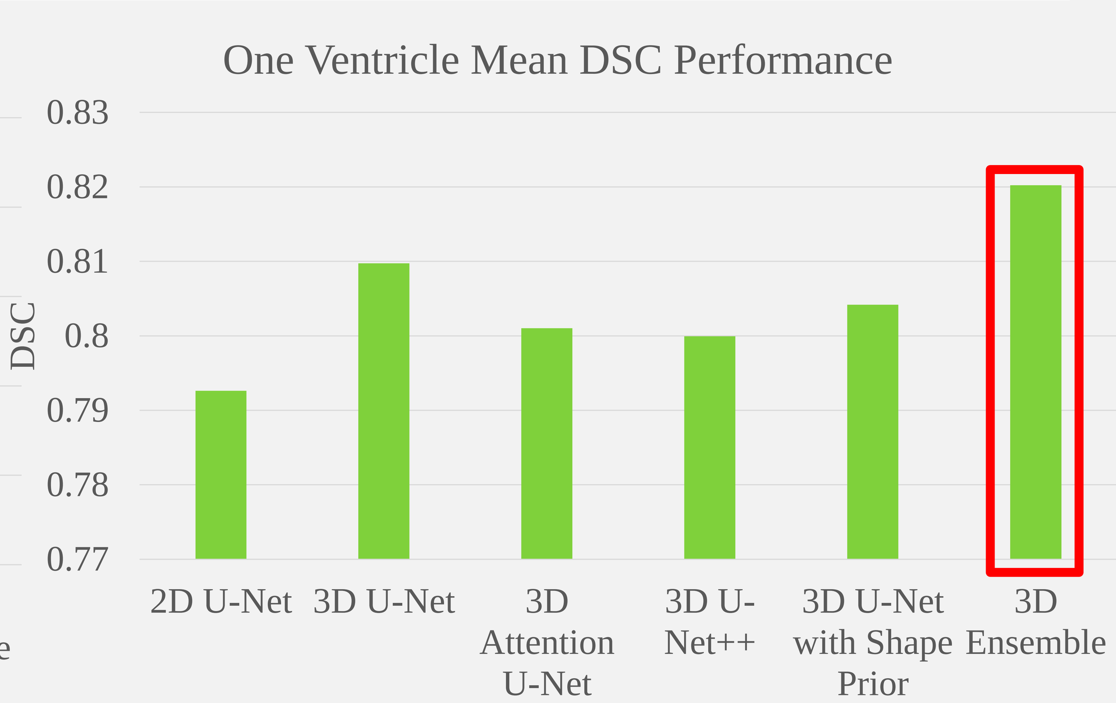
Ensemble Model & Pipeline

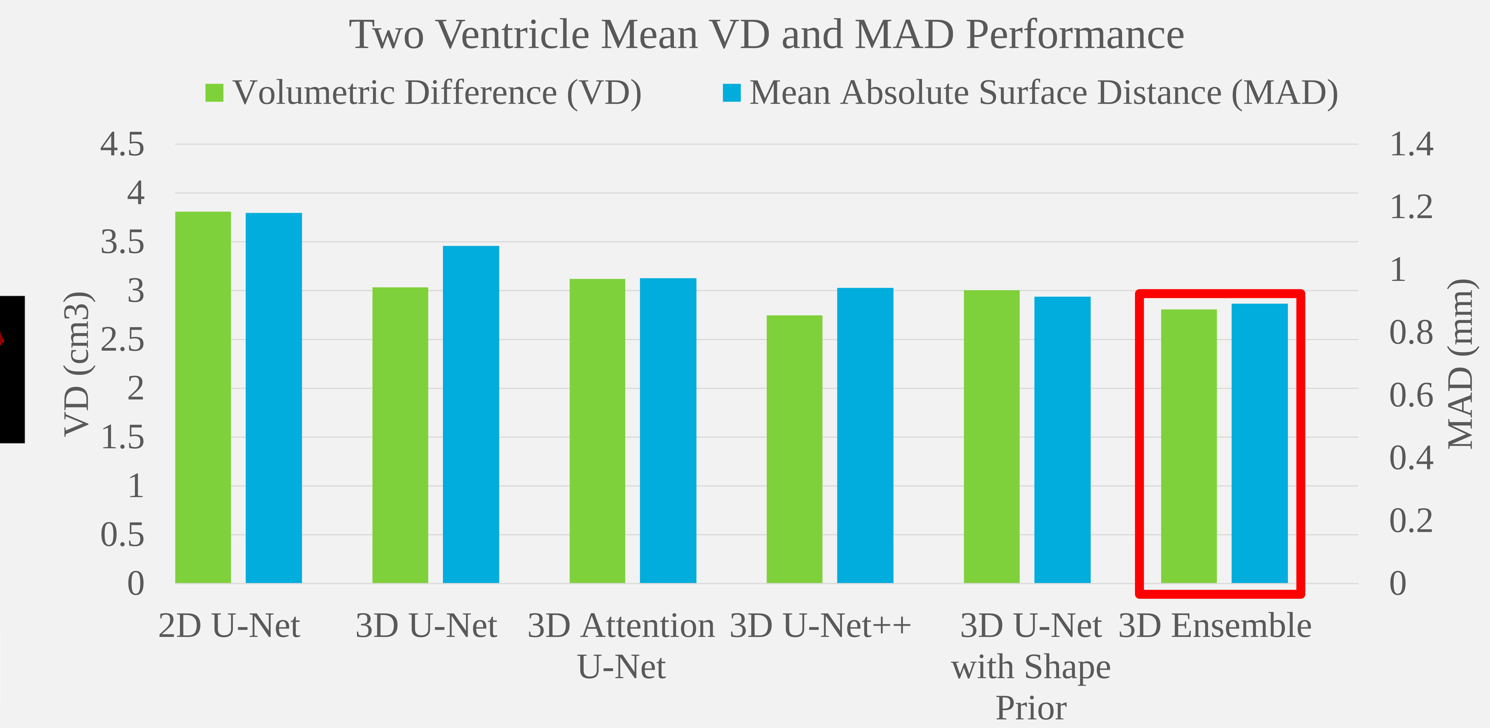
The ensemble model was implemented using three 3D U-Net models, each with their own distinct inductive bias'. The images were first resized to 128x128x128 and normalized. Data augmentation was used to help the small sample size and imbalanced data including translation and reflection about the ventricle line of symmetry. The pre-processed data was inputted into each of the 3D U-Net++, 3D Attention U-Net and 3D U-Net with an autoencoder shape prior embedded in the loss function. A mean voting strategy was used between each of the three models. All images were resized back to their original size, a threshold was applied and the largest objects in the image were kept only.

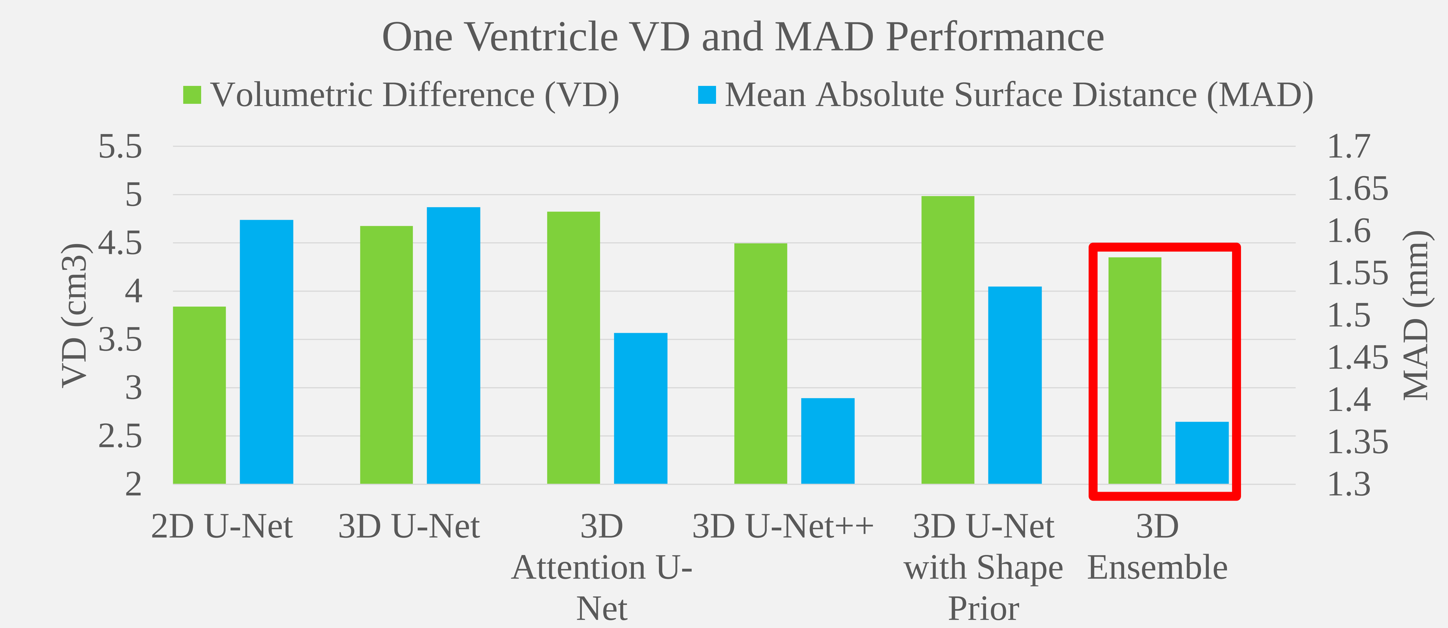
Experiments

Hyperparameters on each model was tuned and 5-fold cross validation was then applied. A total of 165 images were used in the folds (25 extra images were used as validation when training the folds). Models were trained until training performance reached a plateau and the best performing model on the validation set was selected. The ensemble performance was compared to each stand-alone model as well as a vanilla 3D U-Net and the 2D multiplane U-Net model we created from our previous work.



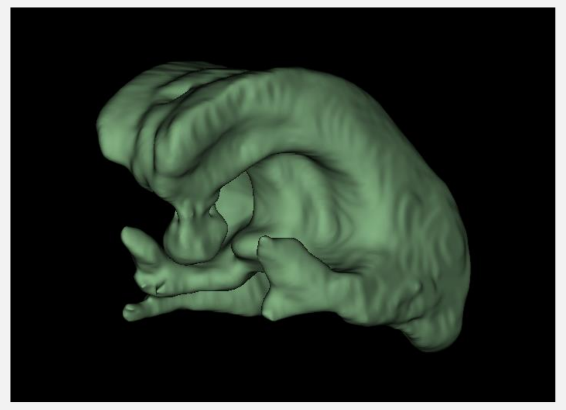




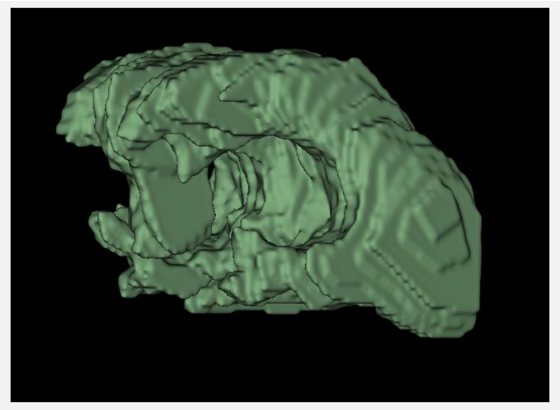


RESULTS

Shown in the bar graphs are our results on the two ventricle data and one ventricle data. We reported results using Dice Similarity Coefficient (DSC), Mean Absolute Surface Distance (MAD) and Absolute Volumetric Difference (VD). The ensemble model took on average 5 seconds to pre-process, segment and post-process each image, significantly faster than current methods which take over 45 minutes per image.



Example Ensemble Predicted



Ground Truth

CONCLUSIONS & SIGNIFICANCE

IVH in neonates is a serious problem which needs to be acted upon quickly so our results show that deep learning can provide fast results at point of care to help clinicians choose the best treatment plan. Our work reports automatic segmentation results from the largest number of images and patients reported; 190 images of 30 patients used and test results provided using 165 3D volumes total from cross-validation. We are also the first group to segment 3D US images which only contain one ventricle (caused by limited FOV).

Acknowledgments: NSERC Discovery Grant, CIHR, OGS, Compute Canada (SHARCNET and Calcul Quebec)