Supplement 1

Instructions to the readers of CQ500 dataset

1.1 Introduction

In this study, we benchmark the performance of the model against that of a panel of radiologists. For the same, here are the guidelines and protocols for the study listed out in the form of FAQs. If you have any further questions, please email to any of the following email ids:

- Sasank: sasank.chilamkurthy@qure.ai
- Rohit: rohit.ghosh@qure.ai

1.2 Marking hemorrhages

1.2.1 Which are the type of hemorrhages we're trying to mark?

We're trying to look at only intracranial hemorrhages which specifically includes 5 types of hemorrhage - intracerebral, intraventricular, extradural, subdural and subarachnoid. We are not looking into non hemorhagic contusions for this study. This also implies we are not looking at extra-cranial hemorrhages like soft tissue hematoma, hemosinus etc.

1.2.2 What about hemorrhagic contusions?

Please check intraparenchymal hemorrhage but please do mention 'hemorrhagic contusion' in remarks box. Are chronic bleeds to be marked and if so, when to mark chronic box? Please consider chronic bleeds (esp, extradural, subdural) as positive and check the corresponding boxes. If there's a chronic component to any hemorrhage in an image, please select chronic box.

1.2.3 Do I need to draw out the hemorrhage locations?

No, for the purpose of this study we're only measuring if algorithm can predict the presence or absence of hemorrhages. So just ticking the checkbox corresponding to each box is sufficient for the study. We however expect you to select the hemisphere ('Right' or 'Left') for hemorrhage that you find.

1.2.4 When do I mark right and when do I mark left?

If there's even a single type of hemorrhage in the right hemisphere please tick the box for right and similarly if there's even a single hemorrhage in left hemisphere please tick the box corresponding to left

What happens if the hemorrhage is located centrally?

In case any of the hemorrhage is located centrally, please mark both 'right' as well as 'left' in the form.

How do I report if there are more than one locations of any particular hemorrhage?

If there is at least one location of intracranial hemorrhage, then please tick the box corresponding for that hemorrhage and mention details in 'Remarks' field. For location, refer above.

1.2.5 What happens if there are multiple types of hemorrhages?

If there are multiple hemorrhages, please tick all the boxes corresponding to types of hemorrhages that are there.

1.2.6 What if an extraaxial is too small to be differentiated between subdural and extradural?

Please select 'intracranial hemorrhage' and none of the below boxes. Please mention that 'extra-axial hemorrhage is too small' in the remarks box.

1.2.7 Is tumor/infarct with hemorrhagic component an intraparenchymal hemorrhage?

Yes. Any hemorrhage in parenchyma is to be selected as IPH. However please mention special cases like these in the remarks box.

1.3 Marking Fractures

1.3.1 Which are the type of fractures we're trying to mark?

For this study we're trying to differentiate between calvarial fractures and other fractures. So for each fracture noted, you need to select checkboxes corresponding to each type of fracture.

1.3.2 What happens if fracture extends from calvarium to outside?

If the fracture covers any of the calvarial bones, we need to consider that as calvarial fracture as well as other fracture. That would imply that the fracture has been reported inside as well as outside calvarium

1.3.3 What is 'other fracture' or What to mark in case fracture is outside of calvarium?

The primary focus of the study is measure calvarial fractures. But if you have found any fractures outside calvarium, please select 'other fracture' and mention the locations in the box next to the checkbox.

1.3.4 What if there are multiple fractures?

If there is even at least one calvarial fracture please tick the box for calvarial fracture. Same applies for other fractures and you can mention details in 'Remarks' field.

1.4 Marking mass effect & midline shift

1.4.1 What are definitions of mass effect and midline lift? Do I mark the two?

Mass effect is any of local mass effect, ventricular effacement, midline shift or herniation. Midline shift, a particular type of mass effect, is positive if amount of shift is greater than 5mm. Therefore, midline shift will imply mass effect and this is reflected in the portal. When you select midline shift, mass effect is automatically selected.

1.5 Marking other abnormalities & normal images

1.5.1 What to do if there are infarcts, tumours or other abnormalities?

As long as the tumor or other abnormalities like infarcts don't involve hemorrhagic component, they don't need to be reported in this study. In case of such cases, you can just click 'Submit' and move on to the next image as long as there are no fracture, hemorrhages or midline-shift/ mass-effect. You may however mention it in the remarks box.

1.5.2 What to do if the image is completely normal?

In that case, please submit without clicking any boxes.

1.6 Exclusion Criteria & Misc info

Our exclusion criteria:

- Studies which don't have a plain series containing whole brain
- Age of patient less than 7
- Post operative case

1.6.1 Do I have access to clinical history?

In this study, we have no access to patient's clinical history. This is kinda fair because algorithms don't have access to clinical history either.

1.6.2 What is Remarks box for?

This can be for any information that cannot be captured by the form.

- Please mention hemorrhagic contusion/mass lesion with hemorrhagic component/hemorrhagic infarct in special cases of intraparenchymal bleed.
- If extra-axial hemorrhage is so small that you cannot determine the location (subdural or extradural), please mention it in this box.
- Please write why this image is being excluded if any.

Please feel free to write in this box your notes or any messages you want us to read. We will go through all the remarks and come back to you if there are any questions.

Supplement 2

Report Generation

2.1 Introduction

In this supplement we describe the processes that were involved in automated report generation. Firstly, deep learning algorithms were used to predict hemorrhage region and skull stripped intracranial region for a given head ct scan. Then the anatomy image was generated through multi-atlas segmentation. Finally, the anatomy image and the hemorrhage mask were combined to localise the hemorrhage region in brain. We describe each of these three methods in detail below.

2.2 Methods

2.2.1 Skull Stripping

An anonymised dataset containing 78 head CT scans (1608 slices) was used to train and validate a skull-stripping algorithm. The intracranial region was marked out slice by slice in each scan. Then a U-Net[1]-based deep neural network was trained on these annotations to strip the skull from each slice.

This algorithm generates the skull stripped intracranial volume for any given new scan.

2.2.2 Anatomy Mask Generation

We used multi-atlas segmentation[2] on skull masks to produce brain anatomy masks. 5 skull stripped head CT scans S_{1-5} were used as the reference scans. Atlases A_{1-5} for each of these were created by annotating the following 15 intracranial regions.

- Frontal region (Left & Right)
- Temporal region (Left & Right)
- Parietal region (Left & Right)
- Occipital region (Left & Right)
- Capsulo-ganglionic region (Left & Right)
- Brain stem region
- Ventricular region (Left & Right)
- Cerebellar region (Left & Right)

For a new scan, the anatomy mask is generated using the following steps

1. A skull-stripped image S is obtained using deep learning algorithm as described above
2. The 5 skull stripped regions S_{1-5} of annotated scans are registered separately to the S to obtain the corresponding transforms T_{1-5}
3. The transforms T_{1-5} are applied on corresponding atlases A_{1-5} to generate realigned atlases $\hat{A}_{1-5}$
4. For each pixel in the skull stripped region S, final anatomy for the pixel was obtained by majority voting of realigned atlases ($\hat{A}_{1-5}$)

2.2.3 Report Generation

To get the location of hemorrhage mask in brain, k-nearest neighbor (kNN) algorithm was used. The following steps were used to determine the location given a predicted hemorrhage mask and the corresponding anatomy image of the scan generated as in Section 2.2.1:

1. The features used for kNN algorithm were world space coordinates. The corresponding anatomy label for the nearest neighbor of each point in the hemorrhage mask was obtained.
2. The distribution of each anatomy location was obtained for hemorrhage mask points.
3. A threshold on the distribution was set to get the regions affected by hemorrhage

References

[1] Olaf Ronneberger, Philipp Fischer, and Thomas Brox. U-net: Convolutional networks for biomedical image segmentation. In *International Conference on Medical image computing and computer-assisted intervention*, pages 234–241. Springer, 2015.

[2] Juan Eugenio Iglesias and Mert R Sabuncu. Multi-atlas segmentation of biomedical images: a survey. *Medical image analysis*, 24(1):205–219, 2015.