# Assessment of atlas warping of small basal ganglia on Colin27

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Introduction: Deep brain stimulation (DBS) of the basal ganglia structures such as the subthalamic nucleus (STN) is beneficial for patients suffering from symptoms of Parkinson's disease. To ensure accurate DBS electrode placement, localization of the STN and other basal ganglia structures is important, but difficult to achieve with clinical MRI. Warping histological information onto the patient's MRI allows visualization of all structures. Such a method has been developed and validated for the globus pallidus, striatum, and thalamus [1,2] as these structures are visible with high contrast in the T1w image. Due to their large size, these structures drive the registration of the entire atlas volume. Yet, smaller basal ganglia such as STN, red nucleus (RN), and substantia nigra (SN) cannot be validated on T1w data due to lack of contrast (Fig. 1). In this abstract, we evaluate the histological atlas-based registration of STN, RN and SN in the Colin27 MNI atlas using ground-truth labels, manually identified on the T2w Colin volume.

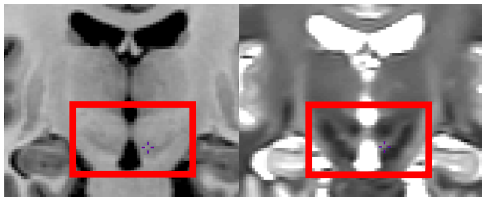

**Figure 1**. The visibility of basal ganglia structures in the T2w contrast (right) which do not appear in the T1w contrast (left).

Method: The T2w Colin12 volume, an average of 12 individual T2w scans, was rigidly registered to T1w Colin27 volume. Using ITK-SNAP (www.itkSNAP.org), one expert painted the labels of the STN, SN, and RN on the T2w Colin12 twice. These structures are then compared to the histological atlas labels available with the T1w Colin27 MNI atlas [2] by calculating the Dice coefficient of overlap ($2*|A \cap B|/|A|+|B|$) and the Jaccard metric (ratio of the intersecting volume to the total manual label volume). We also calculated two position metrics for each structure: COM distance the Euclidean distance between the centre of mass (COM) of the atlas-based and manual segmentations; and COM difference the x-, y-, and z-coordinate differences of the COMs ($COM_{atlas} - COM_{manual}$). To examine volume changes due to registration, and the differences between the atlas and manual labels, we calculated the proportion of volume of each structure with respect to the total volume of all three structures in the hemisphere.

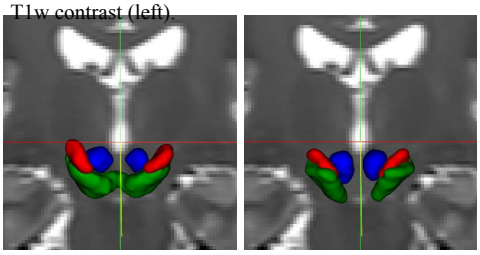

**Figure 2**. RN (blue), SN (green) and STN (red) on Colin27. Left: atlas-based labels. Right: manual labels

Results: Intra-rater reliability for the two manual label painting sessions was sufficient, with Dice coefficient of .84. The T2w Colin image used for painting can be seen on the right of Fig. 1. The atlas-based and manual labels are shown in Fig.2. The overlap statistics and two position metrics are presented in Table 1. The size of the atlas-based structures and the manual labels is shown in Table 2, and their proportions with respect to hemisphere are in Table 3.

| | RN Left | | | RN Right | | | SN Left | | | SN Right | | | STN Left | | | STN Right | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dice | 0.39 | | | 0.43 | | | 0.45 | | | 0.5 | | | 0.52 | | | 0.42 | | |
| Jaccard | 0.28 | | | 0.41 | | | 0.55 | | | 0.57 | | | 0.61 | | | 0.55 | | |
| COM_distance | 3.14 mm | | | 3.09 mm | | | 3.51 mm | | | 3.36 mm | | | 2.41 mm | | | 3.15 mm | | |
| COM_difference (mm) | x | y | z | x | y | z | x | y | z | x | y | z | x | y | z | x | y | z |
| | -0.85 | -2.3 | 1.97 | 1.7 | 1.17 | 2.3 | 1.45 | -3.2 | 0.09 | -1.07 | -3.18 | 0.12 | -1.74 | 0.7 | 1.51 | 1.75 | 0.1 | 2.62 |

Table 1. Overlap and position differences between the atlas-based and manual labels for RN, SN, and STN. Please note that for COM_difference, x-coordinate = left-right direction, y-coordinate=anterior-posterior direction, and z-coordinate=inferior-superior direction.

| | RN Left | RN Right | SN Left | SN Right | STN Left | STN Right |
|---|---|---|---|---|---|---|
| Manual | 249 $mm^3$ | 245 $mm^3$ | 433 $mm^3$ | 535 $mm^3$ | 161 $mm^3$ | 169 $mm^3$ |
| Atlas | 118 $mm^3$ | 221 $mm^3$ | 706 $mm^3$ | 737 $mm^3$ | 207 $mm^3$ | 236 $mm^3$ |
| Atlas (Native) | 239 $mm^3$ | - | 546 $mm^3$ | - | 182 $mm^3$ | - |

Table 2. Total volume of the atlas-based and manual labels for RN, SN, and STN.

| | Left RN | Left SN | Left STN | Right RN | Right SN | Right STN |
|---|---|---|---|---|---|---|
| Manual | 29.5% | 51.4% | 19.1% | 25.8% | 56.4% | 17.8% |
| Atlas | 11.4% | 68.5% | 20.1% | 18.5% | 61.7% | 19.8% |
| Atlas (Native) | 24.7% | 56.5% | 18.8% | - | - | - |

Table 3. Proportional volumes of RN, SN, and STN to the total volume, per hemisphere.

Conclusion and Discussion: Upon visual inspection, the registration-based and manual techniques approximately agree with each other but show distinct differences in shape and location. Quantitatively, geometric differences exist between these two methods: the average Dice overlap value is 0.42, with left RN having the lowest overlap (Table 1). Despite poor Dice overlap values, it is interesting to note that, with the exception of RN, on average 57% of all ground-truth label volumes are covered by the atlas-based labels. This reflects the fact that the manual labels are significantly smaller than the atlas-based labels for both STN and SN (Table 2) and are thus more easily covered by the atlas. On the other hand, atlas-based labels for RN show very poor agreement with manual labels, and are also smaller. Yet, when comparing the distances between COMs, RN is no worse than the average distance of 3.11 mm. Most of the difference in location is in the anterior-posterior direction, where SN and left RN are all more than 2mm anterior than the ground truth. Right RN and STN are also more than 2mm superior. In the left-right direction, the COM of the atlas-based labels for RN and STN are more lateral than the ground truth, while the SN is more medial. Proportionally, the volume of the manually labelled right SN, STN, and RN matches the gold-standard histological atlas in native space very well. The left hemisphere proportions are also similar. Yet, after registration, RN is demonstrably shrunken and SN is inflated. We also note an issue with asymmetry. Although the atlas in native space is symmetric, after registration to Colin27 this is no longer the case and of course the manual labels reflect this. Yet, compared to the manual labels, the RN is even more anterior on the left but more posterior on the right, with a total additional asymmetry beyond the manual of 3.47mm along the y-axis. The volume of the RN is also significantly smaller on the left: although the ground-truth labels for RN are only 4$mm^3$ different, the atlas-based labels are 103$mm^3$ larger in the right RN than the left. Finally, the inflation of SN and shrinkage of RN due to registration is more pronounced in the left hemisphere. Overall, there is an agreement between the atlas-based labels and manual ground-truth, yet the accuracy is not sufficient to delineate the borders of smaller structures for DBS, especially RN. This is a difficult task, given that the nuclei themselves are asymmetric [3], and are variable across subjects [4]. The registration of the of STN, SN, and RN atlas segmentations can be improved, though: a portion of the disagreement could be explained by the limited visibility of these nuclei on the T1w image used to drive registration, as seen in Fig. 1. Generating a T2w appearing pseudo-MRI from the atlas labels and simultaneously registering both pseudo-MRIs to both of Colin27's T1w and T2w structural MRIs is left for future work.

References: 1. Chakravarty et al. NeuroImage 30 (2006) 359 –376; 2. Chakravarty et al. Medical Image Analysis 12 (2008) 713–726; 3. Shen *et al.* Chin Med J (Engl). (2009) 122(20):2438-43; 4. Daniluk *et al*. Acta Neurochir (2010) 152:201–210