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4pSCb13. Multi-subject atlas built from structural tongue magnetic resonance images
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*Magnetic resonance imaging (MRI) is a widely used technology for non-invasive tongue imaging. MRI can detail tongue and muscle shapes and their variability in both healthy and diseased populations. Such detail can aid significantly in the interpretation of muscle interactions in the tongue for both normal and disordered speech production. However, the size or shape of the tongue and muscles may vary from one subject to another. In addition, there exists no comprehensive and systematic framework to assess the difference and variability of tongue and muscles in a normalized space. In the present work, we built a multi-subject atlas from 20 normal subjects that are acquired using structural MRI to offer a normalized space on which all subjects from a target population can be mapped and compared. In order to find accurate one-to-one correspondences, we bounded the tongue so that each volume had the same vocal tract features. For registration, we used symmetric diffeomorphic image registration with a cross-correlation similarity metric, which is widely used in brain image analysis. The atlas facilitates a template-based segmentation in assigning anatomical labels in the images. The tongue atlas is unprecedented and opens new vistas for exploring normal and diseased oral structures and function.

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INTRODUCTION

Magnetic resonance imaging (MRI) has become increasingly important as a means of investigating the structure and function of the human tongue. The tongue, muscle anatomy, and surrounding vocal tract structures can be visualized through structural MRI. In particular, the tongue is a muscular hydrostat, consisting of a variety of intrinsic and extrinsic muscles, which can be categorized based on the shape, location or function.

However, it has been particularly challenging to understand the tongue and muscle shapes and their variability. This is because the complex anatomy of the tongue poses challenges to spatially distinguish each muscle. In addition, the size and shape of the tongue and muscles vary from one subject to another. Hence, the main difficulty in setting such limitations lay in the fact that there is no concrete way to systematically study the similarities and differences of the tongue and muscle shapes. Thus, we sought to address these challenges by the use of a multi-subject tongue atlas, in which a group of individuals can be combined into a common space, allowing us to build a model of “average” tongue anatomy with increased signal-to-noise ratio.

The tongue atlas can be used to define the standard anatomy within which multiple subjects can be mapped in order to directly compare features of interest (e.g., volume change). Further, this novel paradigm can be used for research on tongue motion, for surgical planning, and for diagnosis and prognosis of speech pathology.

METHODS AND MATERIALS

1. Subjects and Data Acquisition

Twenty high-resolution MR datasets are used in these experiments. All MRI scanning is performed on a Siemens 3.0 T Tim Trio system (Siemens Medical Solutions, Malvern, PA) with an 8-channel head and neck coil using a segmented gradient echo sequence. In addition, a T2-weighted Turbo Spin Echo sequence with echo train length of 12 and TE/TR of 62ms/2500ms is used. The field of view is 240 mm×240 mm with a resolution of 256×256. Each data contains a sagittal, coronal, and axial stack of images encompassing the tongue and surrounding structures. The image size for the high-resolution MRI is 256×256×z (z ranges from 10 to 24) with 0.94 mm×0.94 mm in-plane resolution and 3 mm slice thickness. The datasets are acquired at rest position and the subjects are required to remain still from 1.5 to 3 minutes for each orientation.

2. Atlas Generation

The atlas building method is a multi-step procedure comprised of state-of-the-art methods. First, once we acquire a total of twenty normal subjects with three orthogonal stacks (i.e., axial, coronal, and sagittal stacks), we generate a single high-resolution volume via a super-resolution volume reconstruction method [1]. Second, we perform preprocessing to remove artifacts and bound the tongue in order for each stack to have the same anatomical features. Third, we apply an unbiased groupwise registration technique [2] using the symmetric diffeomorphic registration (called SyN) with a cross-correlation similarity metric. In brief, the atlas building involves the following steps: (1) to perform affine transform to register all the images to the template as an initialization, (2) to perform SyN registration to find accurate one-to-one correspondences and (3) finally to construct the tongue atlas by averaging, together with the relevant anatomical correspondences.

3. Muscle Segmentation

In order to calculate the volume change statistics of the tongue and muscles, manual segmentation is carried out in the atlas space by one trained scientist. Since the segmentation task is time-consuming and suffers from inter- and/or intra-observer variability, we use a Random walker-based segmentation method [3] as an initialization. It is a semi-automatic method, allowing users to input seeds to be used as the basis for segmentation. In doing so, it reduce the segmentation time significantly. In addition, it also allows the observer to delineate each muscle consistently.
FIGURE 1. The atlas (first row) and with muscle segmentation (second row): axial, sagittal, and coronal directions are shown in (a), (b), and (c), respectively.

4. Deformation-based Voxel Analysis

To characterize volume changes that indicate anatomical changes, the deformation fields used to find correspondences between volumes are employed to describe global differences in local volume [4]. In order to observe volume changes in each muscle, a partitioning function from the muscle segmentation is used to restrict the muscle region in the atlas space. The Jacobian of the deformation field is then used to characterize volume changes, including local stretching, shearing, and rotation defined at each voxel as follows:

$$J = \begin{bmatrix} \frac{\partial \varphi_x}{\partial x} & \frac{\partial \varphi_x}{\partial y} & \frac{\partial \varphi_x}{\partial z} \\ \frac{\partial \varphi_y}{\partial x} & \frac{\partial \varphi_y}{\partial y} & \frac{\partial \varphi_y}{\partial z} \\ \frac{\partial \varphi_z}{\partial x} & \frac{\partial \varphi_z}{\partial y} & \frac{\partial \varphi_z}{\partial z} \end{bmatrix},$$

where $\varphi$ refers to the transformation from subject to the atlas used in the atlas building. The Jacobian determinant is then computed to calculate the volume changes at each voxel. Then the volume changes in each muscle can be given by

$$\text{Volume Ratio} = \frac{\int_{\Omega} |J(x)| M(x) dx}{\int_{\Omega} M(x) dx},$$

where $|J(x)|$ denotes the Jacobian determinant and $M(x) : \Omega \subset \mathbb{R}^3 \to (0,1)$ denotes the segmented mask region defined in the atlas space $\Omega$. 
RESULTS

Figure 1 shows the resulting atlas and its muscle segmentation using our method. We segmented nine muscles in total including geniohyoid (1), genioglossus (2), hyoglossus (3), digastrics (4), mylohyoid (5), styloglossus (6), inferior longitudinal (7), mucosa and superior longitudinal (8), and velum (9). Figure 2 shows the statistics of the volume ratio for each muscle between the twenty subjects and the atlas. The volume ratios varied from one, indicating that the distribution of muscle volume was not uniform across subjects. But the overall volume ratios were preserved across subjects.

CONCLUSION

In this work, we presented a multi-subject tongue atlas building method from twenty normal subjects. State-of-the-art techniques were employed for accurate super-resolution volume reconstruction and groupwise image registration. The atlas was shown effective for defining standard muscle anatomy. In addition, the atlas would be conducive to structural studies of the tongue and tongue muscle shapes.

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REFERENCES