Semiautomated quantitative analysis of swallow function using dynamic MRI with intensity analysis

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Synopsis
Swallowing dysfunction (dysphagia) is a common problem and a major cause of morbidity in patients who have undergone radiotherapy for head and neck cancer. However, the pathophysiological basis of dysphagia in these patients is poorly understood and may differ between patients, creating a barrier to developing effective treatment strategies. Improved (and ideally quantitative) methods for characterising swallowing function are therefore needed. We describe a method for imaging and analysis of pharyngeal and laryngeal movement during the swallow, based on joint image registration and modelling of intensity changes over a dynamic image series.

Introduction
Swallowing dysfunction (dysphagia) is a common problem and is particularly problematic in patients who have undergone radiotherapy for head and neck cancer. In these patients, dysphagia is thought to arise due to fibrosis of the laryngopharyngeal musculature and loss of sensation at the tongue base, leading to defective swallowing triggering (1,2). However, there is a lack of understanding of the exact contributing factors to swallowing dysfunction in individual patients, limiting efforts to improve or restore swallowing function. One method to improve the understanding of swallowing function is by using video fluoroscopic swallowing examination (VFES) and measuring its usefulness and limitations. In this study, we performed a 3D shape analysis of swallowing function using dynamic MRI images of the swallowing process, and we describe a method for imaging and semi-automated quantitative analysis of swallowing function based on joint registration and modelling of intensity changes over a series of images acquired at high temporal resolution during swallowing.

Methods
Ten adult subjects consisting of five gastrostomy-dependent patients who had undergone radiotherapy for head and neck cancer and five healthy volunteers were imaged on a 3 T Philips Ingenia scanner. Subjects were directed to undertake a series of dry swallows while lying in the scanner, with the scan operator asking the patient to swallow immediately once the sequence had been initiated. Each swallow was imaged using a 20-patient echo acquisition with flip angle 5°, TR 2.25 s, TE 1.26 s, acquisition matrix 120×12, pixel size 0.8×0.8×3.0 mm, slice thickness 10 mm, averages 1. The examination lasted approximately 10 min, during which each of the subjects performed 12 different swallows. The acquisition plane was vertical for each swallow such that three sagittal images (one midsagittal and two paramedian), two axial images (at the level of the tongue base and cricoid cartilage) and one coronal image were acquired. We acquired standard T1-weighted and T1-weighted spin echo images for anatomical assessment.

The sagittal midsagittal images were temporarily cropped to remove long time segments without swallows. The frames closest to the match the closest image to the minimum force of the full-time series was designated as the reference frame. All frames were registered to the reference image using joint registration and modelling of intensity changes over a series of images acquired at high temporal resolution during swallowing.

Results and Discussion
Examples of a series of images from a healthy volunteer are shown in Figure 2: the corresponding deformation field and intensity maps are shown in Figure 3. Example displacement-time and intensity-time plots for a healthy volunteer and a patient with post-radiotherapy dysphagia are shown in Figures 4 and 5. Healthy volunteer swallows typically consist of a single discrete swallowing motion, whereas swallows in post-radiotherapy patients often showed repeated but lower amplitude movements. Registration was accurate in the majority of frames but challenging during the swallowing process, particularly when parts of the swallow missed due to patient movement. In the healthy volunteer, the swallowing motion was reliably captured, as shown in Figure 1.

Conclusions
Quantitative analysis of swallowing function using registration and modelling of intensity changes is feasible in patients and volunteers and is accurate in the majority of frames. Registration can therefore reduce the time taken to analyse the images – which would otherwise require manual ROIs on every frame – and could facilitate the analysis of swallowing function. Capturing the very large movements during the height of the swallow is problematic due to large anatomical deformations and unstructured tissue being pulled into the imaging slice. However, intensity analysis can identify frames with severe intensity changes where registration alone is unable to capture the swallowing motion and provides a complementary approach to assessment of swallowing function.

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References

Figure 1: ROI placement. ROIs were placed on the reference frame image at the symphysis menti (closed circle at anterior end of linear ROI), hyoid (open arrowhead) and pre-epiglottic fat (closed arrowhead). The size of the displacement relative to their starting position was measured for the linear ROI and symphysis menti; the symphysis menti was used as a reference point allowing calculation of the angle of each structure over time. A further ROI (solid line) was placed across the pharynx, and the length and intensity of ROI were measured for each frame.

Figure 2: Example time series of swallowing. Selected images from a healthy volunteer (every other slice shown from left to right, starting with the top row in the middle slices, the pharynx constricts and the hyoid and pre-epiglottic fat elevate.

Figure 3: Deformation maps and intensity change maps. Deformation magnitude is shown in color and is largest in the region of the tongue base and larynx. Intensity changes are shown in (b), in this case, there are small intensity changes in the pharynx due to unstructured tissue being pulled into the imaging slice.

Figure 4: Displacement-time and intensity-time plots for a healthy volunteer. There are large and rapid changes in the position of the hyoid (a) and in the pharyngeal diameter (c) during the swallow. The dysphagia (a) is ‘tensed’ over the registration algorithm but using the intensity changes (b) shows clearly where the swallow occurs (‘extreme’ intensity changes are highlighted in the red line). The pharyngeal constrictor is accurately captured by both the registration (c) and the intensity changes (d).

Figure 5: Displacement-time and intensity-time plots for a patient with dysphagia. There are smaller, periodic changes in hyoid displacement and in the diameter of the oropharynx over the imaging period, which may reflect failure in the registration algorithm. The registration algorithm can accurately capture all of the dysphagia (a) and is also relatively accurate in the pharynx (b) as the large tissue deformations occurring in the normal swallowing do not occur.