Automatic interpretation of 4D computed tomography images in acute stroke

Ajay Patel and Rashindra Manniesing

Fundamental and robust pre-processing of cranial computed tomography exams enables algorithms for automatic analysis and interpretation of diagnostic images in acute stroke.

Strokes—caused by a disturbance of blood supply to the brain—are a leading cause of death and disability worldwide. In the majority of cases, strokes are caused by a blockage of the blood supply (known as an ischemic stroke), but another type of stroke (hemorrhagic stroke) is caused by the rupture of a vessel or aneurysm. Strokes can result in soft tissue damage and loss of brain function. Treatment for acute ischemia consists of administering thrombolytic drugs within four and a half hours of the onset of symptoms. However, this treatment can have disastrous consequences in hemorrhagic strokes. A fast neuroimaging-based patient triage is therefore required for appropriate treatment selection.

Computed tomography (CT) is the first choice of imaging modality for the assessment of acute stroke. CT is widely available in emergency situations, and is a cheaper and faster method than magnetic resonance imaging. CT perfusion (CTP) is a 4D imaging technique in which a contrast agent is used to visualize cerebral hemodynamics over time. Hemodynamic measures, such as cerebral blood flow and cerebral volume, contain information about the extent and severity of an infarcted (oxygen-deprived) region. These measurements can be used to differentiate between brain tissue that is permanently damaged and tissue that is possibly salvageable by reperfusion therapy (restoring blood flow where blood vessels have become blocked). Despite the widespread use of CT, as well as advances in high spatial- and temporal-resolution CT imaging, there has been little progress in the development of algorithms for the automated quantification and analysis of cranial CT exams in acute stroke. Isolation of all pertinent information and cerebral anatomy from 4D images for subsequent post-processing and analysis is the fundamental first step in the development of such algorithms.

To simplify the representation of complex information and to facilitate subsequent image analysis, we classify the voxels of the digital image by assigning them a specific label. This process is called image segmentation. To develop algorithms for acute stroke image analysis, we aim to segment the cranial cavity in 4D cranial CT studies, but this task is complicated by the...
presence of skull fractures, metallic foreign objects, or connected soft tissues such as the eyes (see Figure 1). We propose a method that relies on prior knowledge to define the anatomy included in the cranial cavity. This enables an initial approximation of segmentation of a patient’s cranial cavity, using image registration. The fine details are refined by using the sharp gradient between intracranial tissue and the skull, a characteristic that is inherent in CT imaging.

In our study, we included a large clinical dataset of 573 acute stroke and trauma patients who had received a CT or CTP scan at our hospital. To represent everyday clinical practice, we used limited exclusion criteria when selecting patients. For each patient, manual annotations were also obtained from trained observers to serve as a reference standard.

The initial stage of our method consists of multiatlas registration to the patient image. The most appropriate atlas images are selected, based on anatomical similarity to the patient. This reduces overall computation time, while optimizing performance for each individual patient. The registered atlas labels are then fused to create an initial approximation of the patient’s cranial cavity. The initial segmentation, obtained by multiatlas registration, is then used as an initialization for a multistage geodesic active contour levelset method. A levelset is an evolving surface steered by image information and intrinsic properties (such as curvature) to segment the objects of interest in the image. The gradient in the image, specifically at the inner edge of the skull, is used as a boundary to halt the propagation of the segmentation. The first stage of refinement enables correction of errors that may have been introduced during image registration and also allows fast propagation of the initial segmentation. The

Figure 2. (a, c) CT axial views of example results after multi-atlas registration and label fusion. These images are a good approximation of the cranial cavity of the patient. (b, d) The addition of a levelset considerably improves the final result by correcting minor errors and including fine details.

Figure 3. (Left) Axial, sagittal, and coronal CT views of final cranial cavity segmentations for a patient with a large metallic foreign object between cerebral soft tissue. (Right) The same CT views for a patient with a large hemorrhage who has undergone invasive cranial surgery, leading to substantial deformation of the cranial cavity.
final stage refines the segmentation along the inner boundary of the skull.

The result of the multiatlas registration shows a good degree of overlap with the reference standard, producing a mean Dice similarity coefficient (DSC) of 0.973 ± 0.035. The addition of levelset refinement significantly increases this value to a mean DSC of 0.984 ± 0.026 and improves the final segmentation to a high level of detail (see Figure 2). Our results show a robustness to a large spectrum of anatomical and pathological variations observed in everyday clinical practice (see Figure 3). Furthermore, we demonstrate that the method closely approaches the high performance of expert manual annotation. Further description of our method is currently under review.\(^5\)

In summary, cranial CT exams in everyday clinical practice contain a large variation in anatomy and pathology. We have described a robust and accurate method that segments the cranial cavity in cranial CT studies despite these variations. We have also evaluated this approach in the largest study of its kind. Our study will thus serve as a first step towards automated evaluation and interpretation of cranial CT exams. In future work, we will seek to use our proposed method in the development of algorithms with the aim of improving diagnosis, outcome prediction, and appropriate patient triage.

Author Information

Ajay Patel and Rashindra Manniesing
Diagnostic Image Analysis Group
Department of Radiology and Nuclear Medicine
Radboud University Medical Center
Nijmegen, The Netherlands

References