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Adjustable Computerized Stereotaxic Brain Atlas for Transmission and Emission Tomography

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A computerized brain atlas adjustable to the patient's anatomy would serve serveral purposes. It could be used in stereotaxic surgery. Even more important would be its use in medical imaging to identify various brain structures, such as the basal ganglia and their nuclei, as well as individual cortical gyri. This atlas could be used for additional mapping of nonvisible structures in images obtained with methods having a high spatial resolution, such as computed tomography and nuclear magnetic resonance. Anatomic information obtained in this way might then be transferred to images of low resolution, such as those obtained in positron emission tomography or single-photon emission computed tomography, in order to select anatomically correct regions of interest. The methods used in the construction of such an atlas are briefly described. An attempt to implement such an atlas based on digitized photographs of brain slices is described.

The difficulties encountered with most x-ray techniques in defining and localizing cerebral structures exactly (such as various cerebral nuclei) are partly overcome in functional stereotaxic neurosurgery. This is done by using a stereotaxic atlas and relating the location of the target to interior reference points, such as the anterior and posterior commissures. In order to include individual variations in anatomy, adjustable stereotaxic atlases have been proposed [1–6].

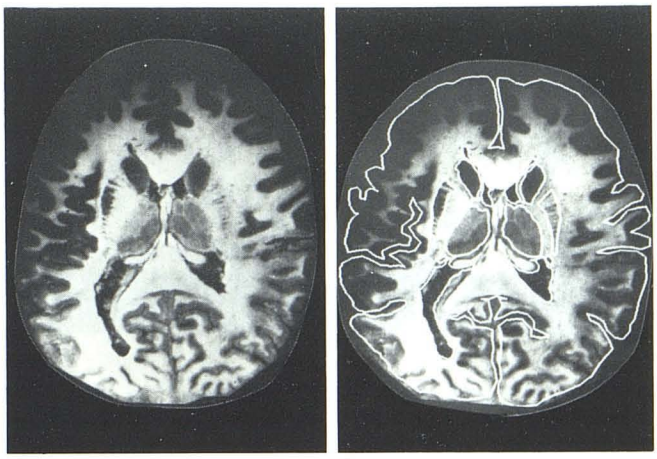
The selection of regions of interest (ROIs) in positron emission tomography (PET) presents a similar problem. The low resolution of this method may make identification of even large structures such as cerebral convolutions and the lateral ventricles impossible. Another, and in principle more important, shortcoming is that the functional image usually obtained in PET cannot be transferred onto an anatomic map without qualification. A high uptake during metabolic studies (e.g., due to variations induced by physiologic stimuli) may make a structure appear abnormally enlarged. This situation can be reversed with a low uptake. Absence of function in an anatomically normal area may be interpreted as absence of the corresponding structures.

Images from radiologic examinations, especially computed tomography (CT), may be used to select the correct ROIs in PET studies. A head fixation technique for exact transfer of positions between CT and PET has been developed [7, 8]. CT gives a good display of the brain surfaces adjacent to the cerebrospinal fluid (CSF) spaces, and, although it has not sufficient contrast resolution to show sharply the boundaries between gray and white matter, it is at present the most convenient method for demonstrating the internal structures of the brain.

If one knows certain reference points or surfaces by CT, such as the inner vault, the walls of the ventricles, the boundaries of the cisterns, or the surface of the insular cortex, it is possible to estimate the positions of various nuclei and cortical gyri, which are seen less well or not at all. This supplemental mapping could be achieved by a computer method that considers individual variations and adjusts a map accordingly, using the CT or nuclear magnetic resonance (NMR) image for locating the reference points and reference surfaces.

Materials and Methods

Brains from cadavers, without clinical signs of brain disease, were fixed in situ using a 10% formalin solution with a pulsating pressure injection technique. A stereotaxic CT investigation was



A B

Fig. 1.—**A**, Digitized photograph of brain specimen used as initial atlas. **B**, Anatomic structures drawn on same slice.

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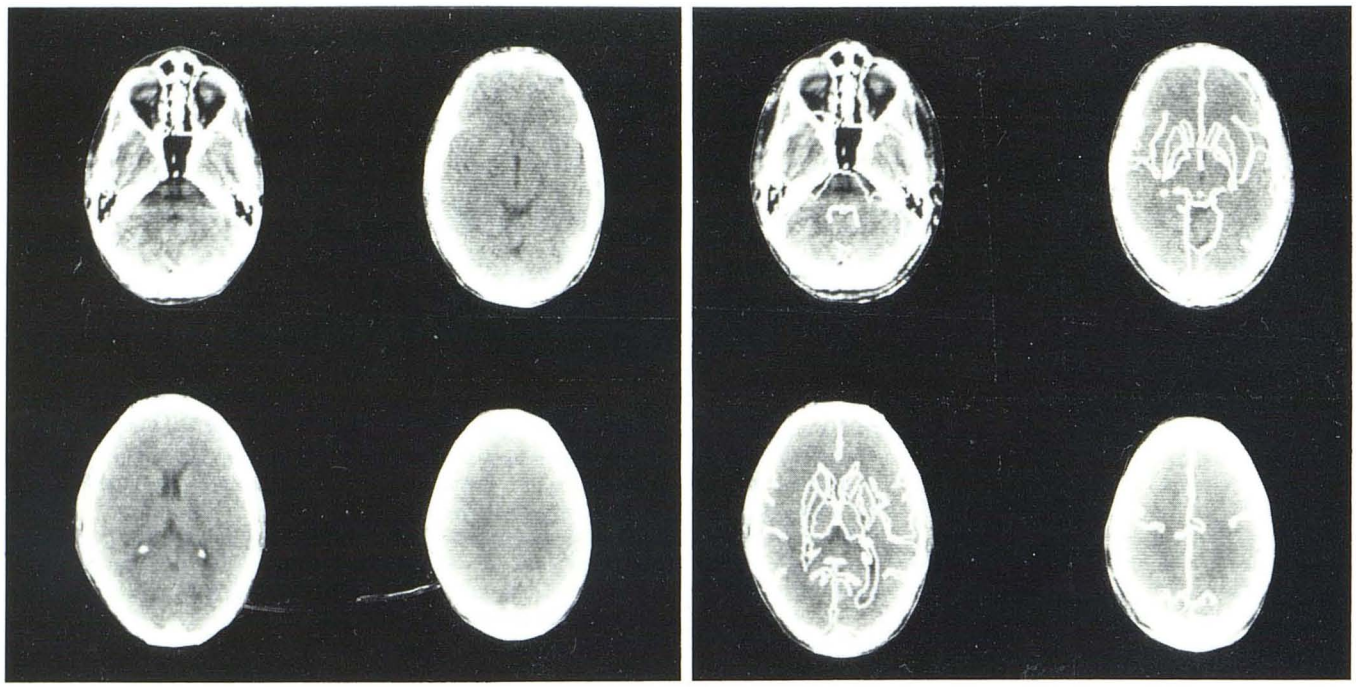
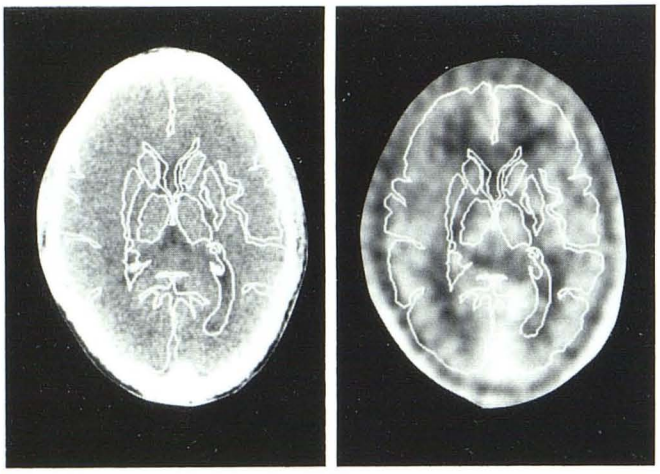


A B

Fig. 2.—**A**, Plain CT slices before atlas "transformation." A global, three-dimensional transformation (including translations, stretchings, and in-plane rotation) of slices in "atlas" was developed from specimen in fig. 1 and a small correction in each slice was made to fit CT anatomy of this patient. **B**, Results. Position determination of main sulci (e.g., central, parietooccipital, and sylvian fissures) serves to delineate borders between frontal, parietal, occipital, and temporal lobes.



A B

Fig. 3.—Structures delineated in lower left image of fig. 2B (**A**) are transferred to PET image (**B**), which demonstrates activity distribution after intravenous injection of ^{11}C-glucose. In this way, atlas may be used to select regions of interest for PET studies. (Atlas images in figs. 2 and 3 are reverse of fig. 1 because CT and PET images are seen from below, specimen slices from above.)

made immediately before and after fixation to exclude any swelling or shrinkage of the brain. The brains were put on the specimen support of the microtome in a frame to make a box specially designed for the purpose. Vertical metal pins were attached to the bottom and the lid of the box to position different colored pieces of fine plastic tubing in a predetermined manner. These served as reference points when the photographs were later digitized. The specimens were embedded in carboxymethyl cellulose and frozen.

Using an LKB cryomicrotome, the brains were cut in the axial plane. This procedure also sectioned the colored tubing in each slice. The top surface of the block was photographed at regular intervals. In this way a series of colored photographs was obtained, 0.25 mm apart.

The photographs were digitized using an 0.25 × 0.25 mm pixel size. Each pixel was represented by its gray scale value from 1 to 256. The total amount of data collected for one brain was at this stage 400 Mbytes. Each digitized image was then transformed in order to bring the reference points into predefined positions (fig. 1A). The image volume, obtained by "stacking" the images on top of each other, could be "cut" in any direction.

The various anatomic structures (i.e., gyri, sulci, cisterns, ventricles, cerebral cortex, white matter, basal ganglia, brainstem, nuclei, etc.), were identified by using the photographs of the slices, the photographs of the brain surfaces, and the reconstructed images of sagittal planes. These structures were labeled and their boundaries determined by means of a graphic display and interactive computer programs (fig. 1B). To obtain consistent data it was important to visualize the regions in sagittal planes. A data base (the individual stereotaxic atlas) was thus created, consisting of the geometric description of the structures and a list of properties for each structure.

The next step was to find a mathematical transformation that could "deform" an atlas illustration so that it agreed with a set of CT images (slices and scout views) in a patient. Using this transformation it was possible to map structures from the atlas onto the CT images. The transformations we used were only translations, stretchings, and planar rotations. The transformations were made in two steps: (1) a global transformation to fit the atlas to all CT images simultaneously and (2) smaller adjustments to the individual images (figs. 2 and 3A). These simple transformations gave a good result in this case. If a brain with larger ventricles had been chosen, however, a deformation of the ventricular system would have been

necessary. Figure 3B shows the atlas transferred onto the corresponding PET image.

Discussion

General methods can be used to obtain the desired transformation [4, 9], assuming "elastic" properties for the atlas and using methods from the theory of elasticity. The "size" of the necessary deformation will determine the accuracy of the transformation. Applying a general method like this directly will, however, cause problems when mapping structures that vary substantially from patient to patient. By first treating easily identifiable structures separately and then using them as reference surfaces, it is possible to extend the range of deformation.

By comparing the results from different individual stereotaxic atlases it will be possible to evaluate the merits and errors of some different transformation methods. A good atlas transformation procedure should be accurate, fast, and should also be applicable to a wide range of individual variations. Efforts to find mathematical transformation formulas are still in progress.

REFERENCES

1. Estrin T, Sclabassi R, Buchness R. Computer graphic applications to neurosurgery. *Medinfo* **1974**;74:831–836
2. Mundinger F, Reinke MA, Hoefer T, Birg W. Determination of intracerebral structures using osseous reference points for computer-aided stereotactic operations. *Appl Neurophysiol* **1976**;38:3–22
3. Tasker RR, Rowe IH, Hawrylyshyn P, Organ LW. Computer mapping of brain-stem sensory centers in man. *J Neurosurg* **1976**;44:458–464
4. Karp P, Bajcsy R, Stein A. Computerized anatomy atlas. In: *Proceedings of the workshop on picture data, description and management, California, August 1980*
5. Giorgi C, Gartibotto G, Garozzo S, Micca G, Piretta G. Three dimensional processing of a stereotactic brain atlas. *Appl Neurophysiol* **1982**;45:419–425
6. Giorgi C, Broggi G, Garibotto G, et al. Three-dimensional neuroanatomic images in CT-guided stereotaxic neurosurgery. *AJNR* **1983**;4:719–721
7. Greitz T, Bergström M, Boethius J, Kingsley D, Ribbe T. Head fixation system for integration of radiodiagnostic and therapeutic procedures. *Neuroradiology* **1980**;19:1–6
8. Bergström M, Boethius J, Eriksson L, Greitz T, Ribbe T, Widen L. Head fixation device for reproducible position alignment in transmission CT and positron emission tomography. *J Comput Assist Tomogr* **1981**;5:136–141
9. Broit C. Optimal registration of deformed images. Thesis, University of Pennsylvania, Philadelphia, **1981**