

Computed tomography dataset analysis for stereotaxic neurosurgery navigation

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Abstract— Experience of design methods of image-guided navigation for stereotaxis neurosurgery is described. The above approach allows obtaining high accuracy to identify spatial the position of the reference stereotactic landmarks. Visualization of the contours of the third ventricle gives the ability to calculate the center of intracerebral stereotactic coordinates system. Use of the proposed techniques in the clinic allows significantly (up to 20%) to improve the effectiveness of stereotactic operations in parkinsonism. Methods for computer tomography image processing are proposed and analyzed. Further, increase accuracy stereotactic targeting functional surgery is associated with the development of machine analysis algorithms tomographic data with a view maximum recognition automation intracerebral landmarks taking into account their individual variability and allow to improve systems for surgical planning by using virtual and full-scale simulation modeling of the main stages a surgical intervention.

Keywords—stereotaxis, visualization, image processing, image-guided surgery, navigation, dataset.

I. INTRODUCTION

Modern neurosurgical equipment is based on the achievements of microelectronics and information technology [1-4]. This applies particularly to the stereotaxic method, which allows for local effects on a specific intracerebral structure using medical imaging methods, a set of navigation calculations and specialized surgical equipment [5, 6].

The effectiveness of stereotactic effects, first of all, depends on the accuracy of the calculation of the geometric characteristics of the area of surgical intervention [6].

Initially, stereotaxic navigation was based on the data of contrast X-ray diffraction, for which the corresponding methods of indirect determination of the localization of the operated intracerebral structures were developed [5].

Geometrical constructions and calculations involved determining the intracerebral stereotactic coordinate system using reference points of the ventricular system of the brain, visualizing the surgical zone using anatomical sections from specialized stereotactic atlases [6, 7], determining the settings of the stereotaxic apparatus and calculating correction factors to reduce distortions on X-ray images.

To date, this invasive technique has been replaced by the use of multimodal data of X-ray helix, magnetic resonance, and positron emission tomography. However, the task of neuronavigation is complicated by the fact that with most functional pathologies, for example, Parkinson's disease, it is impossible to conduct differentiated visualization of the subcortical brain structures, and the principles of scanning and reconstructive imaging make it

difficult to isolate the standard stereotactic reference points needed for performing neuronavigation. The use of non-standard stereotactic landmarks, contrasting visible on tomographic sections, often leads to a decrease in the accuracy of the calculation of the surgical area [7, 8]. Therefore, at the present stage, it is important to solve the problem of adapting highly informative means of mapping intracerebral structures and stereotactic calculations generally accepted in the stereotaxic method, based on reference points of the ventricular system of the brain.

II. FORMULATION OF THE TASK OF RESEARCH

The aim of the work is to develop a universal method for analyzing tomographic data for stereotactic calculations of the coordinates of the surgical area in operations on the structures of the intermediate and midbrain.

The calculation method was developed on the basis of the neurosurgical clinic of Kharkiv National Medical University using intraoperative computer tomograph Somatom Emotion + (Siemens) and a stereotactic Kandel device [9-11], which simulates a polar coordinate system with two angular and one translational degree of freedom for moving the surgical instrument. Fastening the stereotactic apparatus is performed by fixing the carrier platform in a trepanation orifice with a diameter of 25 mm using a collet clamp without using a support frame.

The purpose of stereotactic calculations is to provide high-precision guidance of the surgical instrument in the stereotactic target. To do this, we solve the following problems:

1. Matching coordinate systems of the brain, tomographic imaging, and stereotactic apparatus;
2. Identifying reference points on tomographic images;
3. Construction of intracerebral stereotactic coordinates;
4. Calculation of the geometrical characteristics of the surgical area;
5. The formation of control parameters of the stereotactic apparatus.

To ensure uniqueness during matching of coordinate systems, at the initial stage of the operation, rigid fixation of the patient's head in the aperture of the gantry of the tomograph should be performed with the following conditions:

- installation of the stereotactic apparatus platform perpendicular to the sagittal or frontal planes of the tomographic image coordinate system;
- fixation of X-ray contrast marks on the patient's head

to ensure the possibility of scanning parallel to the orbitomeatal plane;

- receiving survey craniograms in frontal and sagittal projections.

III. RESULTS

In parkinsonism, the structures that should be subjected to destruction or stimulation are characterized by iodine intensive states and are not contrasted by visualization on tomograms. In this case, the method of indirect visualization of the operative zone is applied by binding to the reference points - reference points inside the brain, building the intracerebral coordinate system and determining the area of influence from the averaged data.

The anterior CA and posterior CP white brain adhesions, which are standardly determined by the contours of the 3rd ventricle in the sagittal and frontal projections, are usually used as such reference points [8-10]. An illustration of the mapping of the ventricular system of the brain with the designation of the 3rd ventricle V_3 on tomographic images is shown in Figure 1.

In [8, 10], it was established that the baseline during scanning of the orbitomeatal (Om) plane of the skull, passing through the posterior edge of the orbit and the center of the orifice of the external auditory canal (see Fig. 2, a), is parallel to the CA-CP inter-joint line (the divergence angle is less than 5°).

Therefore, based on the topographic-anatomical configuration of the 3rd ventricle (V_3) (see Fig. 2, a), the technique for determining the CA and CP adhesions by axial sections consists in sequential scanning of the region of the 3rd ventricle with a step of 1 mm parallel to the orbitomeatal plane, measuring the length of the V_3 and determining the slice containing the second (counting from above) local minimum length of the third ventricle V_3 (slice No. 3 in Fig. 2, b). According to the scanning conditions, a horizontal tomographic slice containing the specified local minimum of the V_3 length will be located in the zero horizontal stereotactic plane.

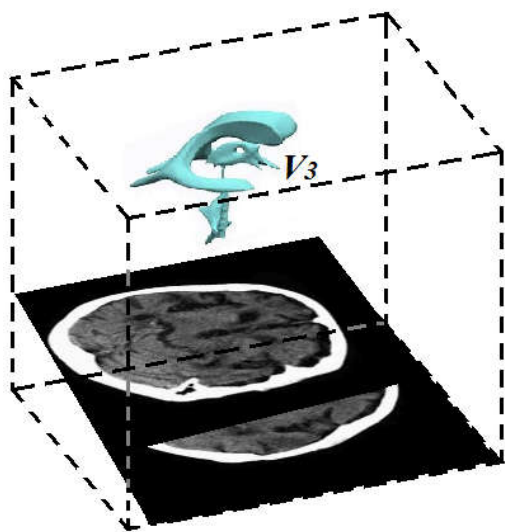


Fig. 1. Schematic visualization of the ventricular system of the brain with the designation of the 3rd ventricle V_3 on tomographic images

Thus, the task of determining the contrasting adjustments of CA and CP is reduced to calculating the length of V_3 (the distance between the anterior and posterior central points of the contour V_3) on the tomograms under study and to isolate the slice containing the second (top) local minimum of the length V_3 . The coordinates of the central points of the anterior and posterior contours of a given V_3 slice, respectively, are taken as the stereotactic coordinates of the location of the SA and CP.

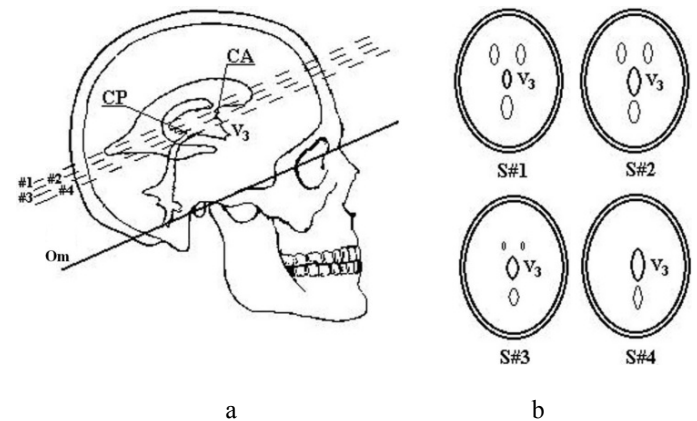


Fig. 2. Illustration of the determination of the main stereotactic landmarks: a is a schematic representation of the scanning plane slices; b is schematic visualization of axial slices with size mapping of the 3rd ventricle V_3 .

Given the importance of correctly finding the coordinates of CA and CP, in order to eliminate the subjectivity of the assessment when determining the length of V_3 , the method of automatic detection of V_3 contours is used, based on carrying out a threshold segmentation of the tomographic image and constructing a binary characteristic function of the form

$$F(i, j) = \begin{cases} 1; & T_1 \leq B(i, j) \leq T_2; \\ 0; & B(i, j) \notin [T_1, T_2], \end{cases}$$

where $B(i, j)$ is the original image of the axial tomographic slice, T_1 and T_2 are threshold values for the ventricular system of the brain [11], determined on the basis of a priori data of a soft-tissue visualization window and histograms refined by extremes (Fig. 3).

To eliminate false local extrema during determining thresholds of segmentation, the histogram is processed with images

$$\overline{G(b)} = \frac{1}{2N+1} \sum_{n=-N}^N G(b+n),$$

where the averaging parameter N is in the range [5-9].

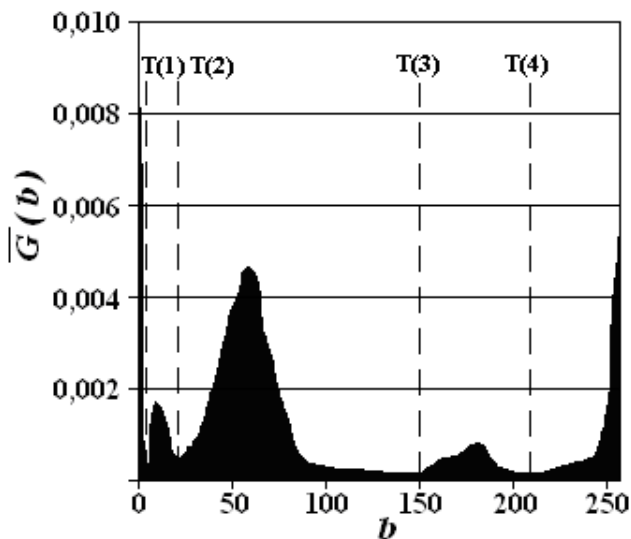


Fig. 3. Averaged histogram of the tomographic slice (T_i is the thresholds for displaying structures of different density).

Fig. 4 shows the process of segmentation of the image of the region of interest (see Fig. 4, a), repeated for the entire set of tomographic data, the construction of a binary characteristic function V_3 (see Fig. 4, b) with the subsequent use of differential operators (see Fig. 4, c) to highlight the contours of V_3 .

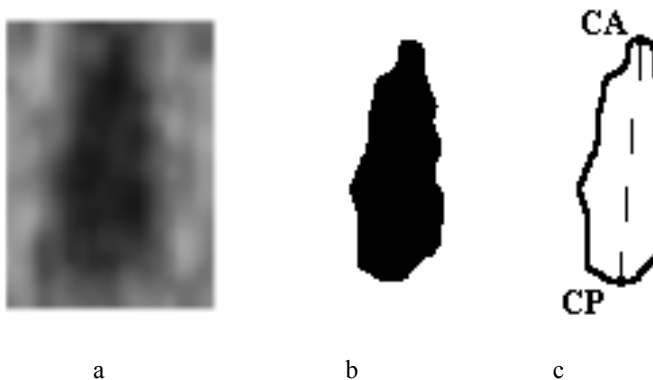


Fig. 4. Illustration of an automatic image segmentation algorithm V_3 : a is the region of interest; b is the visualization of the binary characteristic function; c is the contour image V_3 .

The center of the intracerebral system of stereotactic coordinates is point C located in the middle of the line connecting the spikes (CA–CP lines).

The zero frontal stereotactic plane passes through the center point perpendicular to the line CA–CP. Zero sagittal stereotactic plane passes through the line CA–CP perpendicular to the frontal and horizontal planes. Stereotactic coordinates of the center of the surgical zone are determined relative to point C according to anatomical sections from brain atlases. On the tomographic slice in the zero horizontal plane, calculations of the frontal F and the sagittal C_h stereotactic coordinates are performed, and the horizontal coordinate H is determined from a survey image in the sagittal projection.

Visualization of the sagittal C_h displacement of the target point is carried out in the overview image in the frontal projection. Next, affine transformations of intracerebral coordinates of the point – target location to the coordinates of tomographic images are performed using parallel translation and rotation of the coordinate axes. Additional parameters determine the distance from the target point to support cranial landmarks (outer bone wall boundaries are visualized with the highest sharpness) that facilitates the binding of coordinates. The obtained data on the location of the surgical area is additionally verified by means of functional control.

Virtual modeling guided stereotactic instrument deep into the brain is shown in Fig. 5.

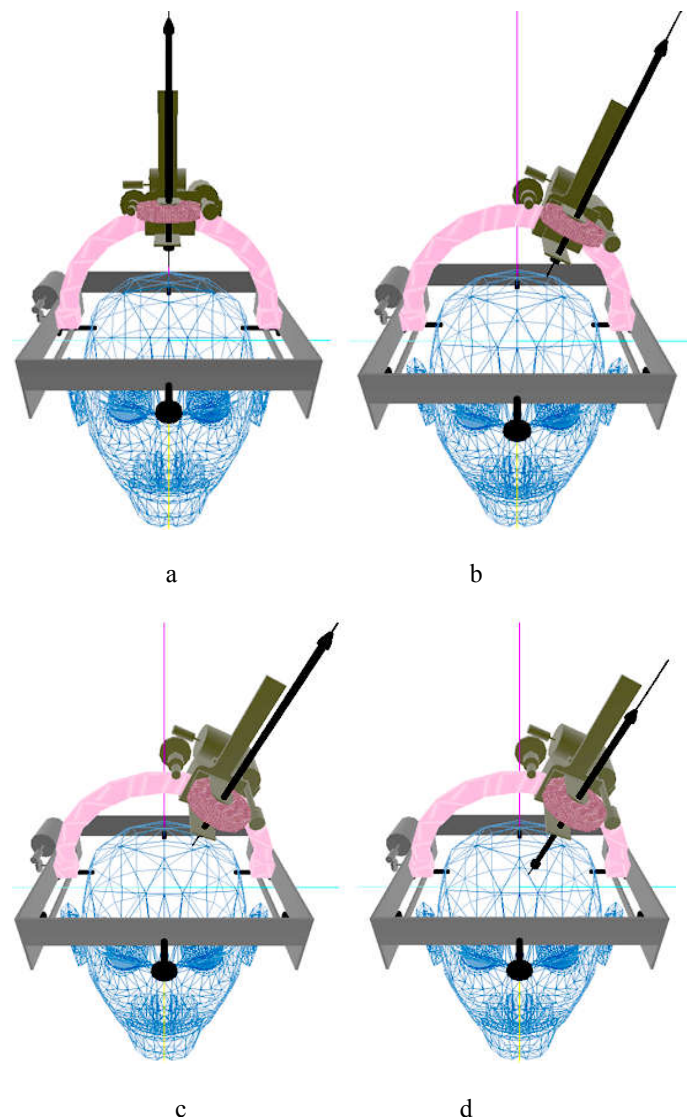


Fig. 5. Stages of virtual guidance of a surgical instrument using a stereotactic apparatus that simulates a polar coordinate system according to Loxel: a is the initial position of the surgical instrument; b is a carriage rotation at an angle of 23° in the frontal plane; c is a frame rotation at an angle of 11° in the sagittal plane; d is the position of the surgical instrument after a 50 mm penetration.

An example of intraoperative navigation under the control of computed tomography is shown in Fig. 6 with a topogram display in the sagittal projection (Fig. 6 a), a tomographic slice at the level of the distal tip of the cannula (Fig. 6 b) and intermediate sections along the cannula (Fig. 6 c and Fig. 6 d).

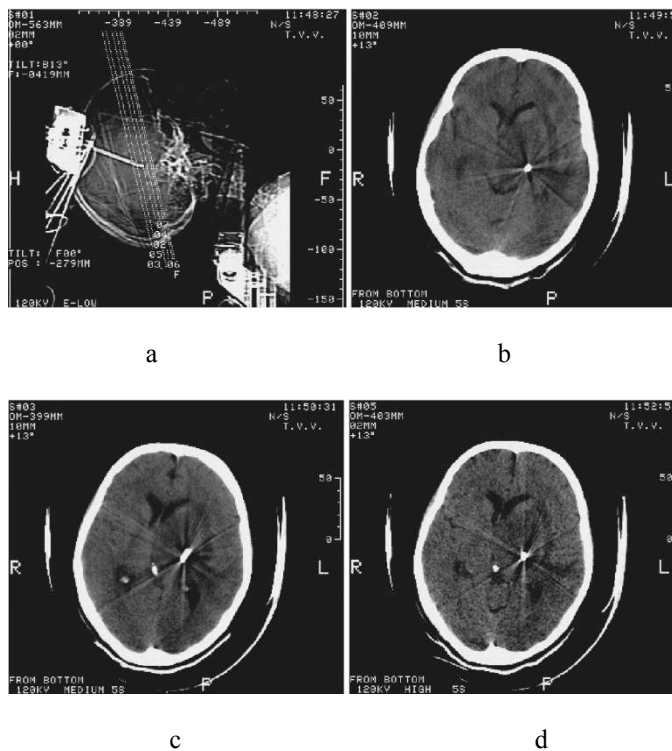


Fig. 6. Carrying out stereotactic biopsy and cryodestruction of a thalamic tumor localization along a calculated low-impact trajectory: a is the topogram in sagittal projection with stereotactic apparatus installed and surgical instrument inserted into the tumor zone; b is the axial SCT slice at the level of the distal tip of a surgical instrument; c, d is intermediate axial SKT-slices along the surgical instrument

Calculation of the surgical instrument guidance parameters using the Kandel stereotactic apparatus is described in detail in the literature [1, 2] and, therefore, does not represent a separate interest.

CONCLUSIONS

This approach allows us to identify with high accuracy the spatial position of the reference stereotactic landmarks.

The visualization of the contours of the third ventricle makes it possible to calculate the locus of the center of the intracerebral system of stereotactic instruments.

Using the proposed approach in the clinic allows significantly (up to 20%) to increase the effectiveness of stereotactic operations in parkinsonism. Further improvement of stereotactic guidance accuracy in functional surgery is associated with the development of algorithms for machine analysis of tomographic data with the aim of maximally automating recognition of intra-cerebral landmarks, taking into account their individual variability, as well as improving operational planning systems that

allow for virtual and full-scale simulation modeling of the main stages of surgical intervention.

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