

Computer-Based Visualization System for the Study of Deep Brain Structures Involved in Parkinson's Disease

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Abstract Parkinson's Disease is characterized by alterations in deep brain structures and pathways involved in movement control. However, the understanding of neuroanatomy and spatial relationships of deep brain structures remains a challenge for medical students. Recent developments in information technology may help provide new instructional material that addresses this problem. This paper aims to develop an interactive and digital tool to enhance the study of the anatomical and functional neurological basis involved in Parkinson's Disease. This tool allows the organization and exploration of complex neuroanatomical contents related with Parkinson's Disease in an attractive and interactive way. Educational implications of this tool are analyzed.

Keywords Medical training · Parkinson's disease · 3D Visualization · Medical education

Introduction

Parkinson's Disease (PD) is a neurodegenerative disorder, which results in the loss of movement control as a consequence of alterations in deep brain structures and specific neuronal pathways [1–6]. A deep knowledge of this disorder is required in most health profession curricula. However, scientific literature has shown difficulties in understanding brain anatomy, spatial relationships and functional pathways of brain structures [7, 8].

Mental reconstruction of complex three-dimensional structures from traditional instructional material such as medical sectional images requires a high cognitive load, which may impair learning [9, 10]. Specifically, Positron Emission Tomography (PET) images have been the most commonly used in the study of activation areas within the brain and movement pathways [11]. However, these functional images lack spatial references that may help students identify which specific brain structures are being activated when movement is occurring or fails to occur.

Computer-based materials based on three-dimensional reconstructions can facilitate the interpretation of complex PET images by providing computer-based three-dimensional models and rich visual representations, therefore reducing the need for mental reconstructions. Furthermore, they can enable the active implication of students in the educational process [9, 10, 12]. For example, graphical user interface eases user navigation and increases the feeling of control and autonomy over both the graphical environment and the contents [13].

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The main objective of this paper was to show a visual and interactive computer-based tool to study anatomical and spatial relationships among deep brain structures involved in PD. In addition, we analyzed the satisfaction level in a sample of students and experienced practitioners who were able to better diagnose PD with this application.

Materials and methods

Image acquisition

Magnetic resonance imaging (MRI) and PET scans were acquired from a 48 year old healthy right-handed male volunteer diagnosed with PD with no history of brain or vascular disease at the Clinical Hospital of Barcelona (Spain). Morphological T1 weighted (MRI) scans were carried out with a (1.5 Tesla) Phillips Medical Systems scanner, and functional positron emission tomography (PET) scans with a Phillips Medical System scanner using fluorine-18 fluorodeoxyglucose ^{18}F -FDG PET and ^{18}F -L-DOPA (18 F-Dopamine PET) images. All sectional images were obtained in Digital Imaging and Communications in Medicine (DICOM) format. Prior to commencing, ethical clearance was sought from the local Ethics Committee following the ethical standards of the World Medical Association established in the 1964 Declaration of Helsinki and subsequent revisions.

Three-dimensional model creation, animations and graphical user interface

High-quality three-dimensional models of superficial and sub-cortical brain structures involved in PD were developed using the AmiraTM software program, version 5.3 (Mercury Computer Systems/TGS, San Diego, CA). The process started with the bilateral segmentation of regions of interest (ROI) for every structure from MRI sections. We defined ROI according to the visible edges of each brain structure, their shape, size and location, under the supervision of an expert neuroanatomist. A unique label field like “putamen nuclei” or “caudate nuclei” was added to each ROI creating a list of brain structures affected in this disorder. Then, an intermediate polygon surface mesh was created for each brain structure using the marching cubes algorithm. Finally, three-dimensional models were exported to Direct X format (3D Exploration software, Right Hemisphere Inc., Auckland, New Zealand). Then, co-registration consisted in unifying information in data sets from the two image modalities used in the study, MRI and PET, which were obtained using craniometric landmarks as parameters in order to guarantee the same angle of acquisition. Mutual information was also maximized by aligning and adjusting the position and orientation of MRI and ^{18}F -DOPA-PET and 18 F-DOPA-PET images. As a result, three-

dimensional models of structures involved in PD were created from morphological MRI images and embedded in functional PET images, where more activated areas appeared in brighter colors, but no clear edges which are required for segmentation were visible. Finally, the anatomical and functional viewer was created using Visual C and ActiveX controls for WindowsTM platforms.

Evaluation

A total of 97 medical students and 60 practitioners were surveyed anonymously using two items designed to rate satisfaction and perception of educational value after exploring the application for 10 min. This student survey had two items: Item#1 stated: “Perceived usefulness of the three-dimensional representations to understand sectional functional images”. Item#2: “Perceived usefulness of the three-dimensional representations to understand basal nuclei”. The practitioner-survey had two items: Item#1: “Perceived usefulness of the three-dimensional representations to improve the diagnosis for basal ganglia lesions”. Item#2: “Perceived usefulness of the three-dimensional representations to improve the diagnostic accuracy for basal ganglia lesions”. Both students and practitioners answered according to the following 7 point Likert-type scale: 1 “completely disagree”, 2 “strongly disagree”, 3 “partially or somewhat agree”, 4 “neither agree nor disagree”, 5 ‘partially or somewhat disagree’, 6 “strongly agree, 7 “completely agree”. All participants gave their informed consent to participate in the study and did not receive any compensation for their participation.

Results

This application was developed for the study of brain structures and control pathways involved in PD and for diagnostic purposes. The viewer included the following elements: 1) three-dimensional models for brain structures related to PD such as basal nuclei, and 2) functional PET images with complementary information about mechanisms involved in the pharmacological treatment of PD (Fig. 1). Additionally, graphic controls were incorporated in the interaction with 3D models and plane cuts were embedded in them (Fig. 2).

Figure 2 shows the interface to regulate 3D model visualization. As shown above, 3D neuroanatomical models were organized in a hierarchical structure. Each model, which can be activated independently, is displayed with a simple mouse click on text/icons within the graphic control. A brief detailed text description is visible when placing the cursor over one of these icons. The following options allow interaction with the models: a) Selection. It is possible to select a particular 3D model corresponding to a specific brain structure by clicking on it. At this point, the hierarchy level is open. b) Texts.

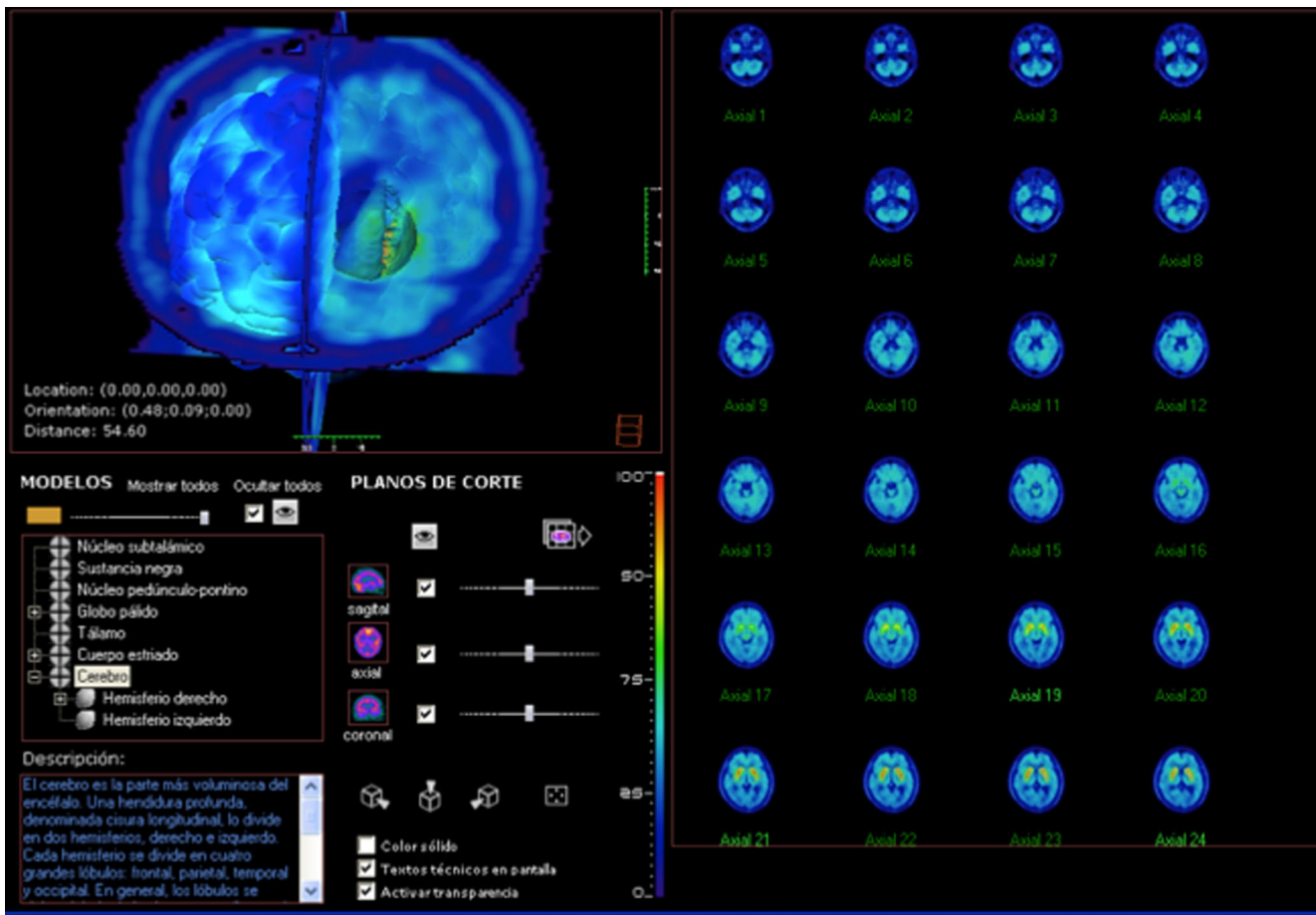


Fig. 1 Three-dimensional visualization of brain along with traditional cross-sectional images

Scientific and technical information of brain structures is available clicking on the option “text”. c) Rotation movements. Any displayed view can be rotated keeping the left mouse button pressed and moving the cursor simultaneously. d) Translation movements. Users should press the mouse button and move the cursor at the same time. e) Zoom in and zoom out. It allows enlargement or reduction of images pressing the secondary mouse button and moving the cursor up (enlargement) or down (reduction). f) Color. It is possible to customize the color of the 3D model to maximize contrast level of the brain structures. g) Transparency. Levels can be changed for each 3D model (Fig. 3).

The anatomical functional viewer interface allows the visualization of 3D embedded models (plane cuts) corresponding to PET sections (Fig. 2). Specifically, three possible orthogonal planes can be independently activated by clicking on them: sagittal plane (lateral), axial plane (horizontal) and coronal plane (frontal). The following interactive features were included: a) Predefined views. An icon is located in the plane cut control area, which enables camera orientation in three predefined views (lateral right-left views and upper view). b) Plane position. A scrollbar allows the position of each plane cut level to shift moving the cursor horizontally. c)

Measurement. A grid icon was included for calculating relative distances between brain structures and functional PET sections. The grid quadrants are defined by the number of rows and columns, which can be changed using the numerical drop box icon located in the control area (Fig. 3).

Additional visualization options include different animations for movement control pathways. Animations that illustrate PD characteristics and current neurobiological mechanisms of typical pharmacological treatments are also included. Sound control and a line of reproduction, which allow moving and finding specific parts within the animation, were added. The visible areas on screen can also be captured and stored as a bitmap (bmp extension).

Students who participated in the test expressed significantly higher satisfaction and perception levels regarding the practical use of the application with the following results: Item # 1: $M=6.6+0.23$; Item # 2: $M=6.8+0.15$ in the previously mentioned 7 point Likert-type scale, where 6 reads “strongly agree, and 7 “completely agree”. Consistently, practitioners who participated in the test also expressed high satisfaction and perception levels regarding the practical use of the application with the following results: Item 1: $M=6.4+0.31$; Item 2: $M=6.2+0.41$.

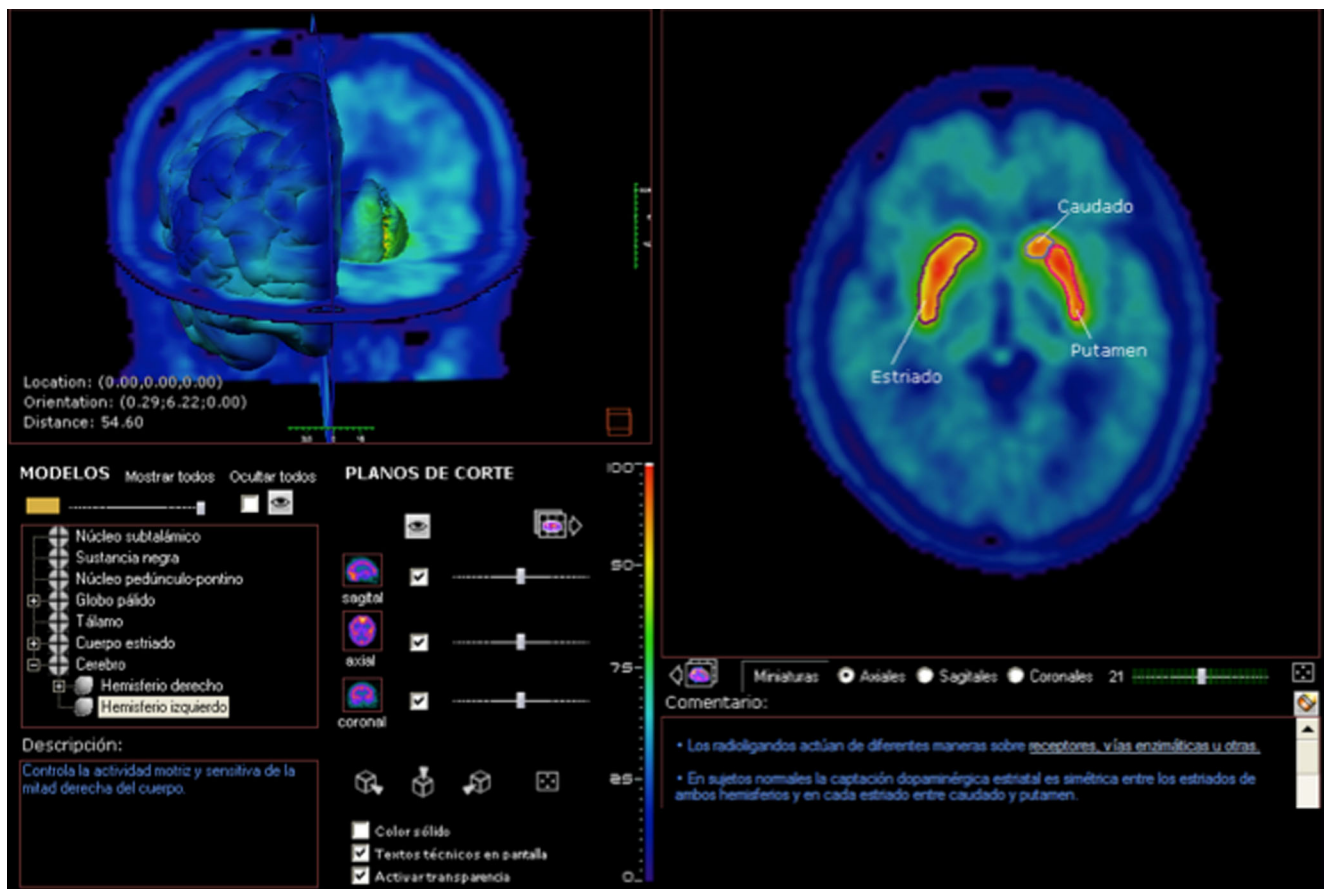


Fig. 2 Viewer graphical user interface and interactive features

Discussion

This study presents a new computer-based tool for learning and teaching the anatomical and functional changes in the brain involved in PD and movement control pathways underlying this disorder. The main strengths of the present digital tool are the following:

First, it provides new means for a student-centered education, which is consistent with the current needs in university education. The inclusion of multiple interactive features also increase the opportunities to better engage students in the learning process overcoming limitations of traditional learning material for these types of contents [12–17].

Second, this tool allows easy manipulation and analysis of complex functional images, which are displayed in a comprehensible, realistic and complete way through three-dimensional models or representations. This development overcame the limitations of traditional bi-dimensional image visualization and/or sequential exploration of images one by one.

Third, this tool is well deemed by students, who assigned a high educational value to it. This result is consistent with previous studies, which highlight the importance of computer-based instructional material, specifically three-

dimensional models and multimedia content in educational settings [18–22]. The ability to simultaneously display multiple brain structures involved in PD according to student's preferences and the functional plane cuts in which they can be embedded.

Fourth, the design and elaboration of this digital resource is consistent with the three organizational systems of working memory: the phonological system for the processing of acoustical information, the visuospatial system for the processing of visual information and the episodic system for the temporal organization of information [23]. This tool includes verbal and visual learning material organized in a dynamic way and is consistent with the cognitive load theory [9–14, 24].

Finally, the most innovative contribution of this tool is the opportunity to add three-dimensional models embedded in functional images PET DOPA and PET FDG. A feature which has not been included in previous studies [18–22, 24].

In recent years, our research group VisualMedSystem has developed multiple computer-based applications for educational purposes, which have recently proven its potential for enhancing the learning of complex neuroanatomical contents when compared with traditional learning methods [14–16]. These educational resources benefit from the latest developments in computer science, specifically, the evolution of

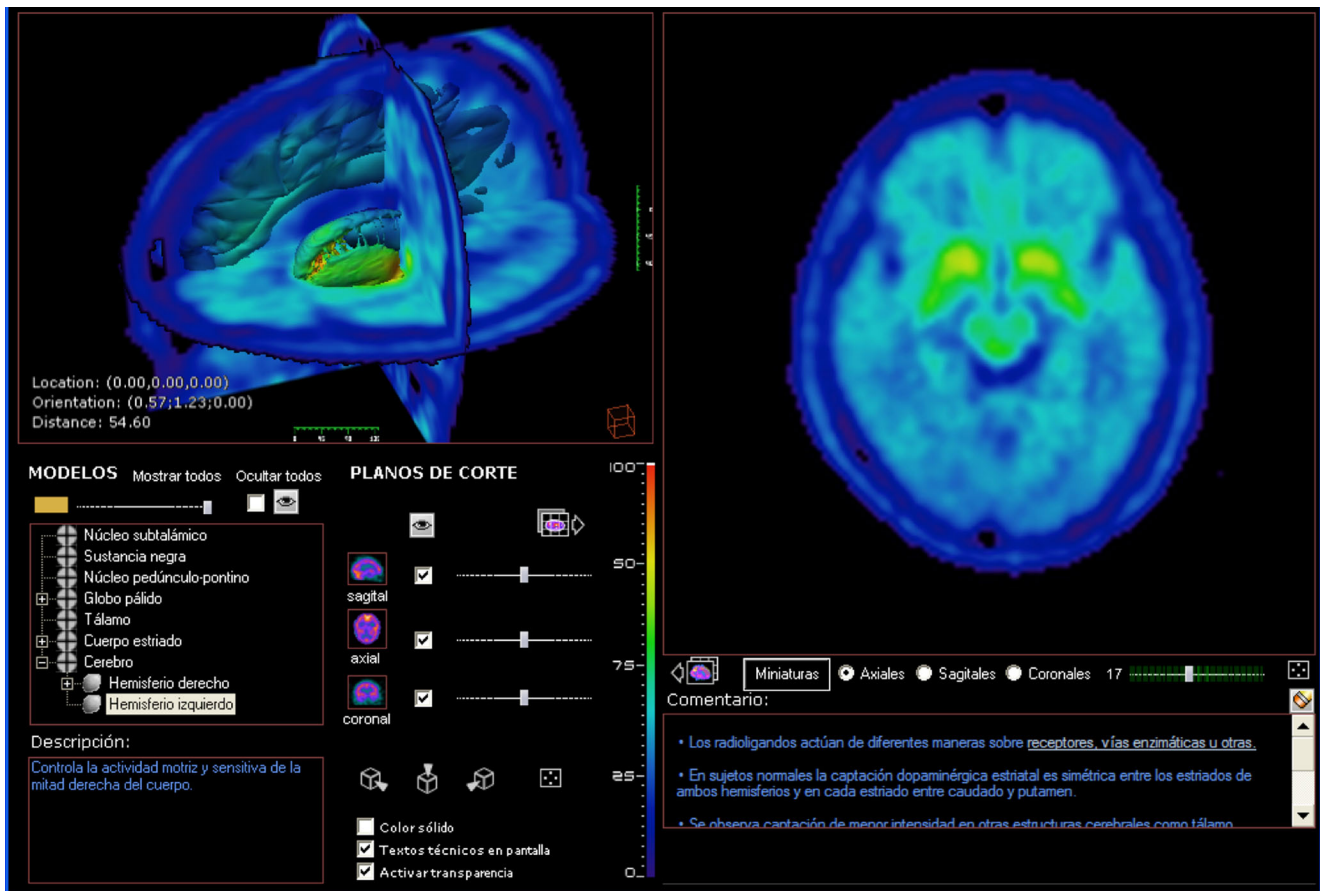


Fig. 3 Three-dimensional representation of brain structures involved in PD embedded in real functional images PET-DOPA (image on the left) and PET-FDG (image on the right)

graphic cards and algorithms for the processing of volumetric data acquired from neuroimaging techniques, such as PET used in the study of PD.

In summary, this study contributes to develop and consolidate current tendencies in learning and teaching, where the role of computer based resources in educational settings is increasing. This study shows how these tools provide a careful display of complex information, which offers an easier and effective way for students to acquire it, overcoming the limitations of traditional learning material in terms of action, and a way to enhance the decision making process and communication between professors and students. It offers new ways to access, explore, represent and deal with the complex information regarding PD, facilitating the human-computer interaction.

In the near future, innovative tools like the one presented in this paper will continue spreading, since they are well accepted by students, basically given the fact that they have grown up in a digital world. Furthermore, we hope that this type of visual and interactive technology becomes an accessible part of the curriculum for healthcare professions in a first approach to PD, providing a true anatomical atlas of the brain structures

involved in PD that can be interactively explored by students.

Three-dimensional visualization plays an important role in improving the way of organizing and communicating the neuroanatomical information associated with PD. It presents complex information in a more realistic way, enhancing the comprehension of anatomical and spatial relationships, in particular complex brain structures involved in basal nuclei. Furthermore, textual and multimedia contents were also included for a more comprehensive illustration of motor pathways. As a result, this tool provides promising computer-based learning material for learning and teaching the neurobiological basis of PD.

In conclusion, computer-based tools are useful to understand the neurobiological mechanisms associated with PD. The integration of neuroanatomical structures and functional brain images with Information and Communications Technology (ICT) tools enables the understanding of complex contents involved in the study of PD. Overall, these applications open new possibilities of learning and knowledge access through a computer based tool that provides three-dimensional models embedded in functional images DOPA PET and 18 F-FDG PET for the study of the neurobiological basis of PD.

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Conflict of interest The authors declare that they have no conflicts of interest.

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