Bridging Neuroanatomy, Neuroradiology and Neurology: Three-Dimensional Interactive Atlas of Neurological Disorders

W.L. NOWINSKI, B.C. CHUA

Biomedical Imaging Laboratory, Agency for Science Technology and Research; Singapore

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SUMMARY – *Understanding brain pathology along with the underlying neuroanatomy and the resulting neurological deficits is of vital importance in medical education and clinical practice. To facilitate and expedite this understanding, we created a three-dimensional (3D) interactive atlas of neurological disorders providing the correspondence between a brain lesion and the resulting disorder(s). The atlas contains a 3D highly parcellated atlas of normal neuroanatomy along with a brain pathology database. Normal neuroanatomy is divided into about 2,300 components, including the cerebrum, cerebellum, brainstem, spinal cord, arteries, veins, dural sinuses, tracts, cranial nerves (CN), white matter, deep gray nuclei, ventricles, visual system, muscles, glands and cervical vertebrae (C1-C5). The brain pathology database contains 144 focal and distributed synthesized lesions (70 vascular, 36 CN-related, and 38 regional anatomy-related), each lesion labeled with the resulting disorder and associated signs, symptoms, and/or syndromes compiled from materials reported in the literature. The initial view of each lesion was preset in terms of its location and size, surrounding surface and sectional (magnetic resonance) neuroanatomy, and labeling of lesion and neuroanatomy. In addition, a glossary of neurological disorders was compiled and for each disorder materials from textbooks were included to provide neurological description. This atlas of neurological disorders is potentially useful to a wide variety of users ranging from medical students, residents and nurses to general practitioners, neuroanatomists, neuroradiologists and neurologists, as it contains both normal (surface and sectional) brain anatomy and pathology correlated with neurological disorders presented in a visual and interactive way.*

Introduction

Understanding brain pathology along with the underlying neuroanatomy and the resulting neurological deficits is of vital importance in medical education and clinical practice. To facilitate and expedite this understanding, we create a three-dimensional (3D) interactive atlas of neurological disorders providing the correspondence between a brain lesion and the resulting disorder(s). We consider the problem of atlas construction from four perspectives: neuroanatomy, neuroradiology, neurology, and computing (meaning that other aspects, such as histology or genetics, are not considered here).

The atlas of neurological disorders contains a 3D highly parcellated atlas of normal neuroanatomy along with a brain pathology database. Normal neuroanatomy is divided into about 2,300 components, including the cerebrum, cerebellum, brainstem, spinal cord, arteries, veins, dural sinuses, tracts, cranial nerves (CN), white matter, deep gray nuclei, ventricles, visual system, muscles, glands, and cervical vertebrae (C1-C5). The brain pathology database contains synthesized brain lesions, each lesion labeled with the resulting disorder and associated signs, symptoms, and/or syndromes.

A portion of the pathology database was created earlier with cerebrovascular disorders¹ and CN-related disorders². This work extends

our previous effort toward neurological disorders related to regional anatomy and presents the complete atlas of neurological disorders.

Material and Method

The atlas design criteria are the following. Anatomically, 3D anatomy surrounding each lesion shall be provided with exploration operations. Radiologically, normal scans are used to present localization of synthesized brain lesions on axial, coronal, and sagittal planes. Neurologically, a variety of brain lesions located all over the brain shall be available along with their neurological description. To make the atlas feasible, we apply a relatively simple geometric modeling of pathology to a biologically complicated problem. Finally, the atlas application shall be efficient and user friendly to run on a standard computer or tablet.

The atlas of neurological disorders contains three main components: an anatomical atlas, a disorder atlas with the pathology database, and an editor to create and label lesions; all three components use the same brain manipulation operations available in the anatomy browser (Figure 1). The construction of the anatomy atlas from 3 and 7 Tesla scans (including design principles, data, methods, tools, anatomical content, features, functionality, content validation, and user interface) was described in detail earlier³⁻⁷. The pathology database correlates brain lesions with the resulting neurological disorders. Each disorder is described in terms of the corresponding signs, symptoms and/or syndromes. An index correlating neuroanatomy with pathology was structured as a list hierarchical with respect to anatomy and linear with respect to disorders. The pathology database contains vascular, CN-related, and regional anatomy-related disorders. As the cerebrovascular disorders¹ and CN-related disorders² were described earlier, here we present disorders resulting from lesions in regional anatomy, including the brainstem (parcellated into the medulla, pons and midbrain), cerebellum, thalamus, hypothalamus, basal ganglia, limbic system, and cerebrum (parcellated into lobes, gyri, and gyri with sulci). For each disorder, its corresponding list of signs, symptoms and/or syndromes was compiled from materials reported in the literature⁸⁻¹⁰. Focal and distributed brain lesions were modeled as spherical, cylindrical or actual (non-deformed) surface white objects. The initial view of each

lesion was preset in terms of its location and size, surrounding surface and sectional (magnetic resonance) neuroanatomy, and labeling of lesion and neuroanatomy. In addition, a glossary of neurological disorders was compiled and for each disorder relevant pages from textbooks⁸⁻¹⁰ were included (in the PDF format) to provide a neurological description.

Results

The latest 3D model of the atlas of normal anatomy is shown in Figure 2. A hierarchical index of regional neuroanatomy along with a linear index of the corresponding neurological disorders was constructed (see Appendix for the complete list of regional anatomy-related disorders and Figure 3 for the sub-lists of signs, symptoms and/or syndromes for selected lesions). The brain pathology database was populated with 144 focal and distributed lesions (70 vascular, 36 CN-related, and 38 regional anatomy-related). The views and labeling of all the lesions were preset. Examples of regional anatomy lesions correlated with the resulting disorders and the surrounding surface and sectional neuroanatomy are presented in Figure 3. These images are composed by means of the anatomy browser which provides operations for: 1) 3D display and manipulation (rotate, zoom, pan, and set view); 2) brain compositing and/or decompositing from groups and/or individual components; 3) two-way mapping (between the 3D view and the index); 4) 3D labeling and highlighting of individual components; 5) 3D brain cutting in seven directions (six orthogonal and one arbitrary); and 6) axial, coronal and/or sagittal magnetic resonance triplanar display.

Discussion

This work bridges neuroanatomy, neuroradiology and neurology in a form of a 3D brain atlas. An initial version of this atlas of neurological disorders was presented as a computer exhibit at the ASNR 2012 (American Society of Neuroradiology) and a positive feedback received (*Summa cum Laude* award) encouraged us to develop it further.

The presented atlas correlates localized brain pathology with both the resulting disorder and the surrounding neuroanatomy. Disorders are described in terms of the resulting signs, symptoms and/or syndromes. The atlas also provides

Figure 1 Simplified schematic (conceptual) architecture of the atlas of neurological disorders.

Figure 3 Illustration of pathology in regional anatomy → correlated with the resulting disorder and the surrounding surface and sectional neuroanatomy. Focal and distributed lesions are presented as spherical or actual (non-deformed) surface white objects. The orientation box in the top-left corner provides the viewing direction (S – superior, I – inferior, A – anterior, P – posterior, L – left, and R – right). A lesion located in: a) lateral medulla; b) lateral pons; c) ventral midbrain; d) cerebellum; e) thalamus; f) lateral geniculate body; g) anterior preoptic hypothalamus; h) whole basal ganglia; i) subthalamic nucleus; j) amygdala; k) limbic system (temporal lobe); l) cerebrum (precentral gyrus).

Figure 2 3D atlas of normal anatomy (the left head muscles, cerebrum and white matter are hidden).

A

B

E

F

I

J

3D interactive display both of labeled pathology and neuroanatomy, freely composed by the investigator. The preset views with labeled pathology and neuroanatomy facilitate and expedite the use of this atlas, while allowing the investigator to promptly update a studied 3D scene, if necessary. The textbook materials and glossary complement the 3D atlas. To the best of our knowledge, this is the first 3D, interactive atlas of neurological disorders.

This work attempts to model a complicated biological problem with simplified geometric modeling, inevitably resulting in certain limitations, some of them already discussed earlier^{1,2}. The current design criteria were assumed to balance between atlas complexity and accuracy, and its feasibility and performance on a standard personal computer and a tablet (whose version is under development). The anatomical atlas has been under continuous extension and enhancement, however, an extension of the (3D) pathology database is not so straightforward and one of the reasons is limited relevant literature¹. One of the solutions enabling enhancement of this work is to link this 3D atlas with case studies, such as¹¹. Though this source does not contain complete 3D information on lesions, it substantially complements our work in terms of clinical findings, multi-modal imaging findings, diagnosis,

differential diagnosis, etiology, gross and microscopic pathology, treatment, complications, and prognosis.

Conclusions

The atlas of neurological disorders provides disorder-localization relationships along with neuroanatomy exploration. It presents 144 focal and distributed brain lesions in 3D, labeled with the resulting disorders and associated signs, symptoms and/or syndromes along with the surrounding neuroanatomy parcellated into about 2,300 components.

The atlas is potentially useful to a wide variety of users ranging from medical students, residents and nurses to general practitioners, neuroanatomists, neuroradiologists and neurologists, as it contains both normal (surface and sectional) brain anatomy and pathology correlated with neurological disorders presented in a visual and interactive way.

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Wieslaw L. Nowinski, DSc, PhD
Biomedical Imaging Lab, Agency for Science
Technology and Research
30 Biopolis Street, #07-01 Matrix
Singapore 138671
Tel.: + 65 64788404
Fax: + 65 64789049
E-mail: wieslaw@sbic.a-star.edu.sg

Appendix Index of regional neuroanatomy along with the corresponding neurological disorders, hierarchical with respect to anatomy and linear with respect to disorders (in italics).

Brainstem	(sympathetic nervous system)
Lateral medulla	<i>Disturbances of heart (rise) rate and blood pressure</i>
<i>Lateral medullary (Wallenberg) syndrome</i>	Paraventricular and anterior or lateral hypothalamus
Medial medulla	(parasympathetic nervous system)
<i>Medial medullary (Dejerine) syndrome</i>	<i>Disturbances of heart (fall) rate and blood pressure</i>
<i>Bilateral lesions of the medial medulla</i>	Supraoptic and paraventricular hypothalamic nuclei
Lateral pons	<i>Disturbances of water balance</i>
<i>Lateral pontine (Millard-Gubler) syndrome</i>	Ventromedial hypothalamic nuclei
Medial pons	<i>Disturbances of nutritional intake regulation</i>
<i>Medial pontine syndrome</i>	Ventromedial hypothalamic region
Ventral midbrain	<i>Disturbances of emotional behavior</i>
<i>Ventral midbrain (Weber) syndrome</i>	Hypothalamic-pituitary axis
Central midbrain (tegmentum)	<i>Hormonal disturbances</i>
<i>Central midbrain (tegmental) (Benedikt) syndrome</i>	Basal ganglia
Dorsal midbrain	Whole basal ganglia
<i>Dorsal midbrain (Parinaud) syndrome</i>	<i>Hypokinesia-hypertonia syndrome (parkinsonism)</i>
Cerebellum	<i>Hyperkinesia-hypotonia syndrome</i>
<i>Cerebellar disease</i>	<i>Wilson disease</i>
<i>Midline cerebellar disease</i>	Subthalamic nucleus
<i>Lateral (hemispheric) cerebellar disease</i>	<i>Contralateral hemiballism</i>
Thalamus	Limbic system
Ventral posterior thalamic nucleus (VPL, VPM)	Amygdaloid nucleus
<i>Sensory disturbances</i>	<i>Disturbances of emotion and emotional behavior</i>
Ventral anterior and ventral lateral thalamic nuclei (VA, VL)	<i>Disturbances of autonomic function</i>
<i>Motor disturbances</i>	Temporal lobe (limbic system)
Intralaminar thalamic nuclei	<i>Disturbances of memory</i>
<i>Disturbances of alertness</i>	Cerebrum
Anterior and dorsomedial thalamic nuclei	Frontal lobe
<i>Affective disturbances</i>	<i>Frontal lobe syndrome</i>
Bilateral dorsomedial thalamic nucleus	Precentral gyrus
<i>Memory disturbances</i>	<i>Precentral gyrus syndrome</i>
Lateral geniculate body (LGB)	Parietal lobe
<i>Visual disturbances</i>	<i>Parietal lobe syndrome</i>
Hypothalamus	Temporal lobe
Anterior preoptic hypothalamus	<i>Temporal lobe syndrome</i>
<i>Disturbances of temperature loss regulation</i>	Occipital lobe
Posterior hypothalamus	<i>Occipital lobe syndrome</i>
<i>Disturbances of temperature conservation regulation</i>	Bioccipital lobes
Ventromedial and posterior hypothalamus	<i>Anton syndrome</i>