D782–D785 Nucleic Acids Research, 2009, Vol. 37, Database issue *Published online 3 October 2008*
doi:10.1093/nar/gkn613

BodyParts3D: 3D structure database for anatomical concepts

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Received August 15, 2008; Revised September 8, 2008; Accepted September 9, 2008

ABSTRACT

BodyParts3D is a dictionary-type database for anatomy in which anatomical concepts are represented by 3D structure data that specify corresponding segments of a 3D whole-body model for an adult human male. It encompasses morphological and geometrical knowledge in anatomy and complements ontological representation. Moreover, BodyParts3D introduces a universal coordinate system in human anatomy, which may facilitate management of samples and data in biomedical research and clinical practice. As of today, 382 anatomical concepts, sufficient for mapping materials in most molecular medicine experiments, have been specified. Expansion of the dictionary by adding further segments and details to the whole-body model will continue in collaboration with clinical researchers until sufficient resolution and accuracy for most clinical application are achieved. BodyParts3D is accessible at: http://lifesciencedb.jp/ag/bp3d/.

WHY BodyParts3D IS NEEDED

Anatomical knowledge is an essential reference for communicating and reasoning about objects and events in the human body. Accordingly, explicit representation of this knowledge allows computational manipulation of data, literature and clinical records and benefits biomedical research and practice in many ways. Anatomy ontology, symbolic representation of concepts and relationships, is a widely accepted approach for this goal. An obvious drawback in symbolic representation is its limited power in representing physical specification of the body, i.e. morphology of body parts and topological and geometrical relationships among the parts, although such physical specification comprises a substantial amount of human anatomical knowledge (1,2). To obtain both computable and comprehensible representation of a physical specification of a 'standard human body', we started constructing an anatomical dictionary by specifying body parts through segmentation of a 3D model of a male human body (Figure 1). Although laborious, dictionary construction was straightforward because all spatial relationships among segments are originally represented in the whole-body model. If desired, any specific relationship can be extracted by computation afterwards (Table 1). Conversely, ontological representation of categorical, taxonomical and developmental knowledge about human body parts in a symbolic structure functions complementary to BodyParts3D.

CONSTRUCTION PROCESS OF BodyParts3D

BodyParts3D was constructed on the framework of a voxel human model for electromagnetic dosimetry, 'TARO' (4), which was created from a whole-body set of 2 mm interval MRI images of a male volunteer. Additional anatomical segmentations were introduced in the original data (phase 1). Then, missing details were supplemented and blurred contours were clarified using a 3D editing program by referring to textbooks, atlases and mock-up models by medical illustrators (phase 2). Further segmentation and data modification will continue in collaboration with clinical researchers until sufficient concept coverage is achieved (phase 3). Consistent inclusion of non-material entities such as surfaces, holes, notches, edges and points and also discrimination of *bona fide* boundaries and conceptual boundaries will be the challenge in expanding the dictionary. The number of concepts specified as of today is shown for each anatomical system and construction phase in Figure 2.

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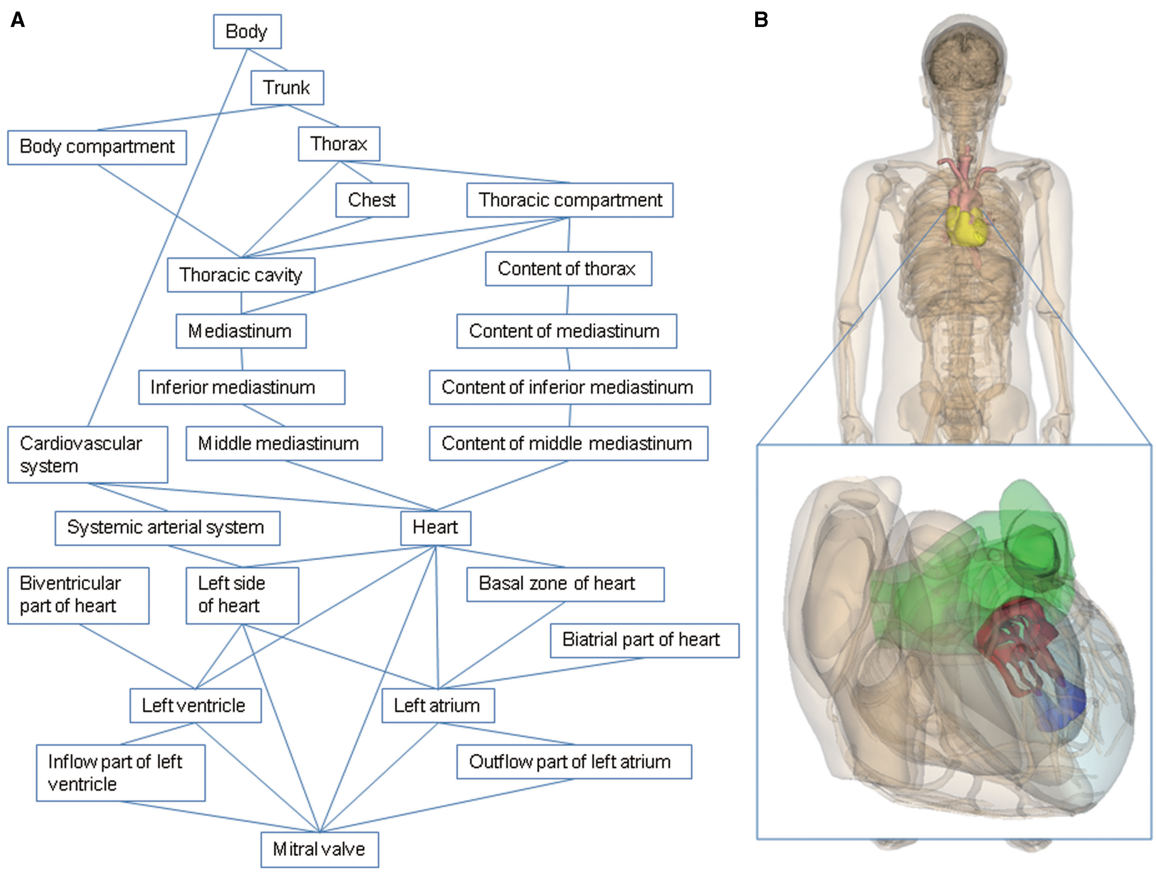


Figure 1. Representations of the mitral valve in (**A**) representative anatomy ontology, the Foundation Model of Anatomy (FMA) (1) and (**B**) BodyParts3D. FMA data were obtained from Open Biomedical Ontologies (OBO) (http://www.obofoundry.org/cgi-bin/detail.cgi?id=fma_lite). In (B), mitral valve (red) is shown with left posterior papillary muscle (deep blue) on the background of left ventricle (light blue), and left atrium (green) in the blow up image. Behind this, heart (yellow) is shown on the background of mediastinum (pink).

Table 1. Examples of topological relationships in BodyParts3D for deriving relationships between entity A and B defined in FMA

Relationships in FMA	Topological relationships in BodyParts3D
A has part B	$\partial A \cap B^\circ = \emptyset$ and $A^\circ \cap B^\circ \neq \emptyset$ and $A^\circ \cap \partial B \neq \emptyset$ (contains, covers)
A part of B (inverse of A has part B)	$\partial A \cap B^\circ \neq \emptyset$ and $A^\circ \cap B^\circ \neq \emptyset$ and $A^\circ \cap \partial B = \emptyset$ (inside, coveredBy)
A continuous with B A attaches to B	$\partial A \cap \partial B \neq \emptyset$ and $\partial A \cap B^\circ = \emptyset$ and $A^\circ \cap B^\circ = \emptyset$ and $A^\circ \cap \partial B = \emptyset$ (meet)

$\partial A/\partial B$ denotes the boundary of 3D object A/B, whereas A°/B° is the interior of the object. The topological relationships are defined by Rogers *et al.* (3).

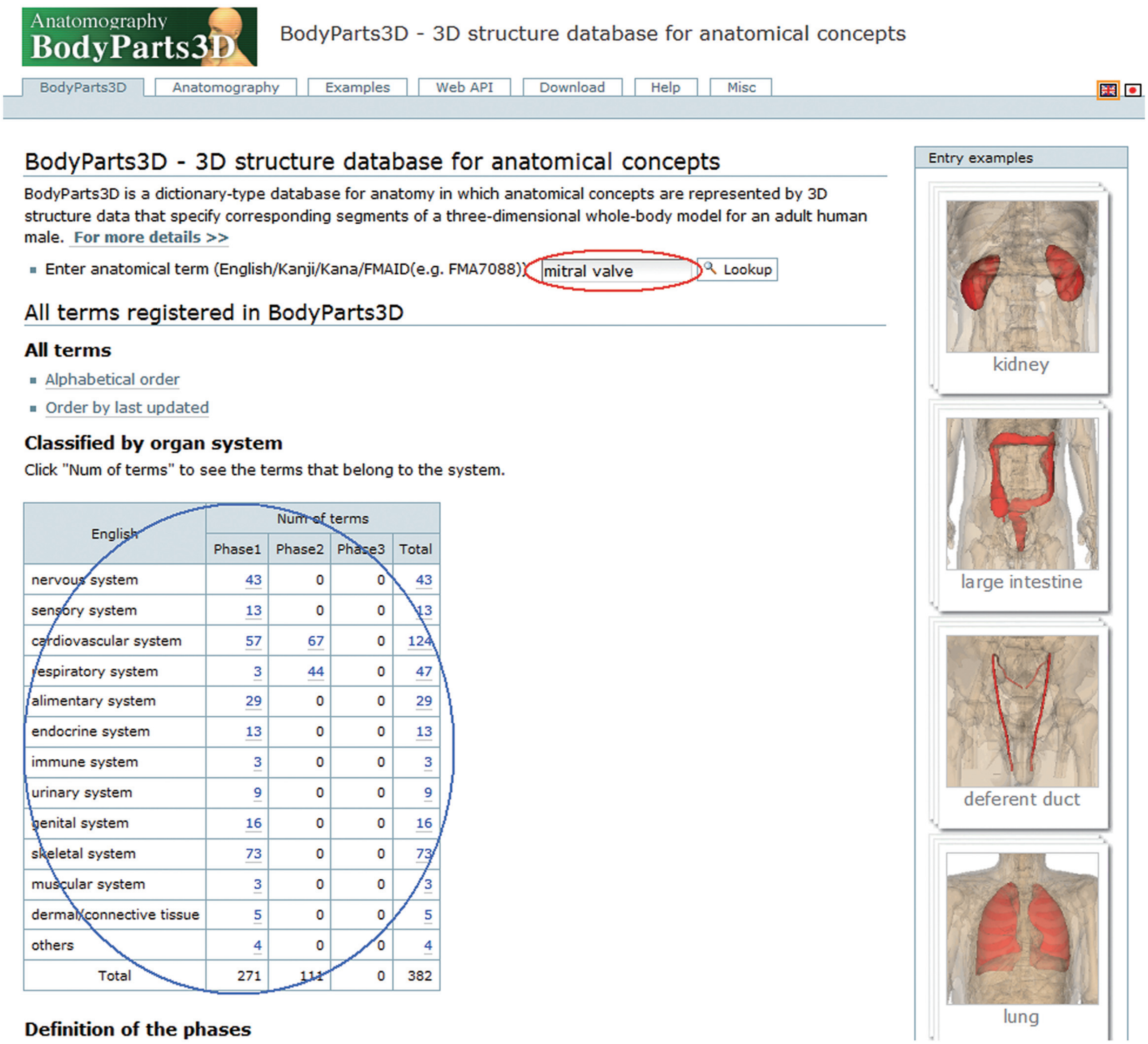
USE OF BodyParts3D

Besides being a computable and comprehensible anatomy dictionary, BodyParts3D introduces a coordinate system to the human body structure. A relevant body position in medical research and practice, such as the origin of biopsy specimen or tumor location, can be indexed correctly, with respect to the relative spatial relation to surrounding anatomical markers, in this coordinate system for management, sharing and visualization of data. A rendering server that allows users to specify a relevant position in the context of graphical images of the desired body region with the desired body parts, as shown in Figures 1 and 2, will facilitate such indexing as well as visualization.

RELATED WORKS

There are several high-resolution 3D atlases based on a set of photographic images of serial sections of a male cadaver, published from the National Library of Medicine's 'Visible Human Project' (http://www.nlm.nih.gov/research/visible/visible_human.html). One prominent example is 'Voxel-Man' (5,6), in which a 3D model was extensively segmented and mapped to structured vocabulary. Interestingly, in these works, realistic details, such as small vasculature and texture of tissues, were pursued at the expense of handy data size. Consequently, down stream applications required a computer dedicated for graphics in a local environment and are limited to educational settings or surgical simulations rather than for the prosper of bioinformatics and information sharing. In addition, it is reported that there are several independent nonpublic projects that constructed detailed 3D human models for various purposes (7).

The Edinburgh Mouse Atlas Project (EMAP) (8) is a project in mouse genomics that elegantly uses



English	Num of terms			
	Phase1	Phase2	Phase3	Total
nervous system	43	0	0	43
sensory system	13	0	0	13
cardiovascular system	57	67	0	124
respiratory system	3	44	0	47
alimentary system	29	0	0	29
endocrine system	13	0	0	13
immune system	3	0	0	3
urinary system	9	0	0	9
genital system	16	0	0	16
skeletal system	73	0	0	73
muscular system	3	0	0	3
dermal/connective tissue	5	0	0	5
others	4	0	0	4
Total	271	111	0	382

Figure 2. Keyword search form (red circle) and summary of registered concepts grouped by organ system and phase (blue circle) (http://lifesciencedb.jp/ag/bp3d/).

a combination of ontology and a 3D modeling. In EMAP, the segmentation of the 3D model was limited to early embryonic stages because the primary aim of the modeling was to introduce visible and sharable demarcation to embryonic body parts that have no morphologically clear borders.

DATA ACCESS AND AVAILABILITY

In BodyParts3D, 3D data files are labeled with corresponding Foundation Model of Anatomy (FMA) concept IDs and indexed with their English synonyms as well as their Japanese equivalents for searching (Figure 2). Each 3D data file in BodyParts3D whose phase is two or higher is downloadable in VTK or STL formats at: http://lifesciencedb.jp/ag/bp3d/download/.

CONCLUSIONS

Universally, our bodies are composed of the same set of anatomically discriminable body parts that amounts as many as independent anatomical concepts, being arranged in the same geometrical positions. In this sense, the person-to-person difference in our body structure is not much larger than item-to-item difference in the structure of manufactured products of the same model.

In manufacturing, engineering drawings, often called as blueprints, are central in sharing information among designers, manufactures and repairing mechanics. BodyParts3D is designed to serve as such blueprints in information sharing among basic and applied medical researchers and clinicians. BodyParts3D can be accessed at: http://lifesciencedb.jp/ag/bp3d/.

ACKNOWLEDGEMENTS

We thank 'TARO' development team for generously providing their data. 'TARO' is a voxel model phantom for radio-frequency electromagnetic-field dosimetry developed by the National Institute of Information and Communications Technology (NICT), Kitasato University, Keio University and Tokyo Metropolitan Univ.

FUNDING

Funding for open access charge: The Integrated Database Project, Ministry of Education, Culture, Sports, Science and Technology of Japan.

Conflict of interest statement. None declared.

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