SCIENTIFIC ARTICLE

Digital Three-Dimensional Model of Lumbar Region 4–5 and its Adjacent Structures Based on a Virtual Chinese Human

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Objective: To study the methods for constructing a digitized three-dimensional (3D) model of a virtual lumbar region and its adjacent structures in order to assist anatomical study and virtual surgery.

Methods: Images of DSCF5375-p1 to DSCF5745-p1 were taken from the database of the digitized Virtual Chinese human of Southern Medical University in Guangzhou. This region encompasses the superior facet joint of L₄ to the inferior edge of the intervertebral body of L₅. The regions of interest were interactively segmented from the images utilizing Adobe Photoshop software. The images were further processed using format conversion and segmentation. Finally, a 3D model of the L_{4–5} region and its neighboring structures was reconstructed with the assistance of Mimics 10.01 software.

Results: A digitized 3D model of this part of the virtual lumbar spine and its adjacent structures was reconstructed. This model allows all constructed structures to be displayed individually or jointly, moved or rotated arbitrarily, setting of different transparencies and convenient measurement of the diameters and angles of the reconstructed structures. The 3D model precisely displays the anatomical relationships between all structures and provides a reliable 3D model for a spinal endoscopic surgery simulation system.

Conclusion: Visualization of the digitized 3D reconstruction of the virtual lower lumbar region displays this region and its adjacent structures stereoscopically and in actuality, thus providing morphological data concerning anatomy, image diagnosis and virtual operations in this region.

Key words: Chinese digital human; Lumbar; Three-dimensional reconstruction; Visualization

Introduction

With ongoing developments in medical science, more conditions of the lumbar region are managed surgically. Compared with general surgery, lumbar surgery is difficult and risky. In order to reduce the incidence of adverse events associated with lumbar surgery, thorough understanding of the anatomical structure of this region is very important. The digitized lumbar model shows a virtual lower lumbar region and

its adjacent structures, thus providing morphological data concerning the anatomy of this region.

We used Mimics 10.01 software to construct a digital three-dimensional model of the lower lumbar region. The resulting models are surface models. Unlike volume models, surface models of small file size can be distributed, opened, rotated, and modified in real time, even online. These features make surface models suitable for an interactive simulation

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system. Thus, three-dimensional (3D) model of the lower lumbar spine and its adjacent structures can be used for development of a variety of virtual operative procedures such as a spinal endoscopic surgery simulation system.

To create the 3D reconstruction, we selected images of the superior facet joint of L₄ to the inferior edge of the intervertebral body of L₅ from the database of the digitized Virtual Chinese human of the Southern Medical University in Guangzhou. The aim of this study was to build a three-dimensional model of the L₄₋₅ region and its adjacent structures that could provide accurate details for an anatomical basis for surgical planning and achieve lumbar simulation on a computer.

Materials and Methods

Image Preprocess

One hundred and eighty-five transverse cross-sectional images of the L₄₋₅ region were selected from the database of the digitized Virtual Chinese human of the Southern Medical University in Guangzhou, the thickness of each image being 1 mm. This database was derived from an average-sized, well-developed cadaver without organic lesions. The cadaver had been enrolled in the cadaver donation program. Both the subject and her relatives had donated the body to the Virtual Chinese human project, in accordance with the scientific ethic regulations of the Southern Medical University and Chinese Ethics Committee.

The cadaver of the data set used in the present study was 19 years old at the time of death, had no lesions in any organ, was 155 cm tall and weighed 46 kg. The subject is representative of completely normal adult Asian female anatomy. The cross-sections were photographed with a digital camera at a high-resolution of 3024 × 2016 pixels, each TIFF file occupying 17.5 Mb. With Photoshop software, the images were registered through four reserved fiducial rods and the background removed with the magnetic lasso tool and magic wand tool.

Images of DSCF5375-p1 to DSCF5745-p1 were taken from the database of the digitized Virtual Chinese human of Southern Medical University in Guangzhou. These images encompass the superior facet joint of L₄ to the inferior edge of the intervertebral body of L₅. 185 images were selected (one image from every two slices).

Segmentation

The regions of interest were segmented interactively from the images utilizing Adobe Photoshop software. The images were then processed using Photoshop features such as registration, segmentation and format conversion. With the tools provided by Photoshop software, the contour line of the lower lumbar spine and its adjacent structures, including skeletal, articular, muscular, vascular and nervous components, were processed and saved as a BMP file (Fig. 1).

Three-Dimensional Reconstruction

The segmented images of the various structures were imported into Mimics 10.01 software to complete the 3D reconstruction,

Fig. 1 (a) One of the original images of the Virtual Chinese Human. (b) image of L₄ The same image segmented from the original image with the Photoshop software.

after which the 3D models of the structures were saved. Finally, the 3D models of the various structures that were in STL format were imported into the Mimics 10.01 software. A 3D model of the L₄₋₅ region and its neighboring structures was created and visualization of the digitized virtual lumbar region completed with the assistance of software functional modules (Fig. 2). This reconstruction method, which is called surface rendering 3D reconstruction, is based on a marching cubes algorithm.

Results

The L₄₋₅ digital model was reconstructed using Mimics software and no data loss was detected. It includes all adjacent structures, such as skeletal, articular, muscular, vascular and nervous tissue. The model represents a standard Asian woman (Fig. 3).

The 3D model can be displayed partially, wholly or with some of the structures appearing transparent, and can be observed from any orientation, angle or point of view. All reconstructed structures can be moved or rotated arbitrarily, different transparencies can be set, and the diameters and

Fig. 2 A 3D reconstruction model of the Mimics program user interface on the computer.

angles of the reconstructed structures can be measured conveniently. The 3D model precisely displays the anatomical relationships between all structures and can provide a reliable 3D model for a simulation system for endoscopic spinal surgery (Fig. 4).

Discussion

The Virtual Chinese Human

Serial sectional images of whole cadavers have been become available through the work of four projects: the Visible Human Project (VHP), the Visible Korean, the Chinese Visible Human (CVH), and the Virtual Chinese Human (VCH). The VHP was the first to obtain serially sectional images of whole human cadavers (1994, male; 1995 female)¹. The key technique used for obtaining these sectional images at 0.33–1 mm intervals is to sequentially mill the cadaver that has been frozen in a gelatin solution. This technique was modified by a Korean project in 2002². Subsequently, the methodology was applied by separate groups of Chinese researchers to launch the Chinese Visible Human project and the Virtual Chinese Human in 2003^{3,4}. For the VCH, several unique techniques with new equipment were used to address the limitations of previous projects: the whole cadaver was frozen, embedded, and sectioned in the upright posture to acquire high-quality sectional surfaces with natural body contours.

For this article on the VCH, a female cadaver was studied. The cadaver was a young healthy female; there were no flat back artifacts because the cadaver had been frozen and embedded in the upright position. Sectioned images (intervals, 0.2 mm) were of exceptional quality and resolution (0.1 mm-sized pixels).

Segmentation and Three-Dimensional Reconstruction

In order to construct 3D models of body structures for medical simulation, the outlines of the structures in the sectioned images must be drawn in advance; this segmentation work is mostly manual and is very time-consuming⁵. In the Korea and China projects, the segmented images and the resultant 3D models' software packages have been created over several years.

The VHP was the first study to obtain serially sectioned images of whole cadavers. The aim was to be a milestone in the medical imaging field and anatomy education sphere. It has proved to have wide application⁶. For the Visible Korean, detailed 3D surface models of the cerebrum, ear, liver, gastrointestinal tract, urogenital organs, and lower limbs were built from serial outlines of segmented images^{7–9}. For the CVH, the investigators actively carried out surface and volume reconstruction based on outline images of the cerebrum, nasal and temporal bones, parapharyngeal space, superior mediastinum, heart, liver, prostate and associated neighboring structures for diverse applications^{10–19}. The VCH project has wide

Fig. 3 Three-dimensional model of L₄₋₅. (a) Whole display and (b) illustrating the functions of moving, rotating, scaling, cutting, three-dimensional measurement and multi-display.

applications based on the surface models of various anatomic structures of an individual cadaver. These applications include virtual dissection, virtual endoscopy and motion simulation, as well as game and examination modules²⁰.

Clinical Application of the Digitized Virtual Lumbar

Lumbar surgery is difficult and has a long learning curve because of the complex anatomical structure of this region. Familiarity with the anatomy of the lumbar region, its adjacent organs and the relationships between them are critical for ensuring the success of lumbar surgery. The digitized virtual lower lumbar region provides detailed and commonplace information about the lumbar vertebrae of female Asians. It can be cut from any angle or direction and display any sectional image including orthoslices and oblique slices, thus helping young surgeons to master the anatomy of this region.

Virtual reality surgical simulation is an increasingly promising aspect of clinical anatomical education. The digitized virtual lower lumbar region is a framework for stimulating lumbar surgery such as virtual spinal endoscopic surgery. Young spine surgeons can master the detailed anatomy of lumbar region and the required surgical basic skill by model-based simulation.

Problems

Pathological conditions of the lumbar region generally occur in the L₄₋₅ segments. Because of limited time and manpower, we only completed a 3D reconstruction of L₄₋₅. This is a short-coming of our study. The ultimate goal of our work is to produce a 3D model of the entire spinal column including the

Fig. 4 (a) Three-dimensional model of L₄₋₅ and its adjacent structures such as skeletal, articular, muscular, vascular and nervous tissue. 1, abdominal aorta; 2, vertebral body of L₄; 3, superior articular process of L₄; 4, inferior articular process of L₄; 5, spinous process of L₄; 6, transverse process; 7, spinal cord; 8, nerve root; 9, intervertebral disc of L₄₋₅; 10, vertebral body of L₅; 11, endoscope.

(b) Endoscopic view of simulated virtual endoscopic spinal surgery via a transforaminal approach, showing the endoscope (black cylinder) as inserted through the safe triangle zone, allowing the spine surgeon to remove a herniated nucleus pulposus via virtual endoscopy.

cervical, thoracic and lumbar regions. Moreover, the virtual spinal endoscopic surgery mentioned in this study was only preliminary exploration of virtual surgery. To perfect this approach, there is still a long way to go with further study of the digital spine.

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