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Surface models and gradually peeled volume model to explore hand structures

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ABSTRACT

This study was intended to confirm whether simultaneous examination of surface and volume models contributes to learning of hand structures. Outlines of the skin, muscles, and bones of the right hand were traced in sectioned images of a male cadaver to create surface models of the structures. After the outlines were filled with selected colors, the color-filled sectioned images were stacked to produce a volume model of the hand, from which the skin was gradually peeled. The surface models provided locational orientation of the hand structures such as extrinsic and intrinsic hand muscles, while the peeled volume model revealed the depth of the individual hand structures. In addition, the characteristic appearances of the radial artery and the wrist joint were confirmed. The exploration of the volume model accompanied by equivalent surface models is synergistically helpful for understanding the morphological properties of hand structures.

1. Introduction

Unlike computed tomographs (CTs) or magnetic resonance images (MRIs), serially sectioned images of a cadaver have high resolution and actual body color. Therefore, the sectioned images such as Visible Korean data enable the segmentation and three-dimensional (3D) reconstruction of detailed structures (Park et al., 2005a). Surface models with a small file size can be selected for display and rotated in real time (Shin et al., 2012a; Park et al., 2013; Shin et al., 2015b). On the other hand, volume models with huge voxel information reveal the inside with actual colors (Shin et al., 2014; Kwon et al., 2015, 2016; Chung et al., 2016). To utilize both strong points, in a recent study with the Visible Korean data, surface models and volume model of the foot were constructed and examined simultaneously (Shin et al., 2015a). As a subsequent target, the authors chose the hand, which has complicated extrinsic and intrinsic muscles.

The aim of this study has been to confirm whether various observations of surface and volume models are beneficial to hand anatomy comprehension. To achieve this goal, outlines of the skin, muscles, and bones of a right hand were drawn on the sectioned images and stacked to produce surface models. Concurrently, the sectioned images, including the designated colors of the outlined structures, were stacked to produce a volume model of the hand, from which the skin was then gradually peeled.

2. Materials and methods

In the Visible Korean project, sectioned images (intervals 0.2 mm; pixel size 0.2 mm; color depth 24 bit) were acquired from an entire male cadaver (age 33; height 1.64 m; weight 55 kg) (Park et al., 2005a). We selected 736 sectioned images from the distal part of the radius and ulna to the end of the hand. The target region was only the right hand, so that excessive margins were cropped to reduce the resolution from 3,040 × 2,008 to 479 × 587.

The upper limbs of the subject were not in an anatomical position. The palms were pronated at a 90 degree angle to face the trunk, while the fingers were naturally flexed (Park et al., 2005a). The sectioned images were rotated at a 90° angle to make the palm face the upper side of the pictures (Fig. 1).

2.1. Outlining

We used ready-made outlined images in which the skin, hand muscles (Table 1), hand bones, and radial artery had been drawn almost manually (Park et al., 2005b; Shin et al., 2012b). The intervals of the outlined images were 1 mm; therefore, the number of

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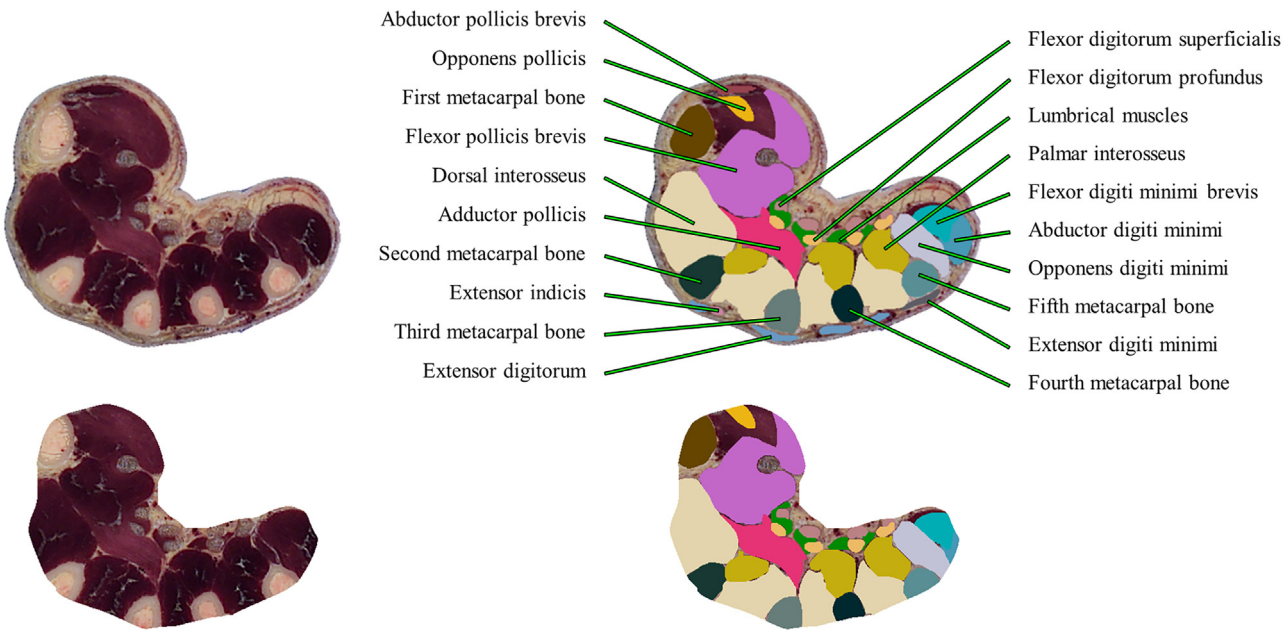

Fig. 1. A sectioned image of the hand (top left) and one overlapped by color-filled outlines (top right). The original images (top row) are shrunk to a thickness of 6 mm (bottom row).

outlined images was not 736 but 148. The outlines were filled with different colors according to the individual components.

2.2. Surface reconstruction

Only the color-filled outlines of the hand structures were stacked. Surface reconstruction of the entire structures was achieved simultaneously using Mimics version 17 (Materialise, Leuven, Belgium). In each surface model, the accumulated outlines were removed, and the triangular surfaces were suitably reduced in number (Shin et al., 2015b; Shin and Park, 2016). The entire surface models of the muscles, bones, and an artery were rotated to produce the dorsal, palmar, radial, and ulnar views (Fig. 2, leftmost column).

Additionally, two axes of the wrist joint were drawn on selected surface models of the bones and the five muscles that end at the metacarpal bones (Fig. 3).

2.3. Volume reconstruction

To reduce the intervals of the outlined images from 1 mm to 0.2 mm, the outlines of the structures were interpolated. The outlines, filled with specific colors, were superimposed on the sectioned images (Fig. 1). The 736 color-filled sectioned images (intervals 0.2 mm; pixel size 0.2 mm) were stacked to build a color-filled volume model (voxel size 0.2 mm) (Shin et al., 2014).

Using an established method (Shin et al., 2014), the color-filled volume model of the hand was peeled to thicknesses of 2 mm, 4 mm, 6 mm, and 8 mm. We examined the peeled volume model in the dorsal, palmar, radial, and ulnar views together with the corresponding surface models (Fig. 2).

3. Results

From the Visible Korean homepage (ranatomy.co.kr), a portable document format (PDF) file was downloadable free of charge by selecting the menu titled "PDF file of 3D models (Male – Hand)." With the PDF file, the surface models of the hand structures (Table 1) can be selected in any combinations, freely rotated, and conveniently zoomed in and zoomed out by manipulating the mouse (Shin et al., 2012a).

The surface models of the hand occupied just 13 MBytes, but one volume model occupied 623 MBytes. The large file size of the volume data was because there were approximately 207 million voxels (voxel size 0.2 mm).

It was beneficial that the tissue colors in the peeled volume model were consistent with those in the original sectioned images and that the segmented structures in the peeled volume model could be easily recognized by the artificial colors inside the outlines (Figs. 1 and 2).

The surface models provided the locational orientation of the hand muscles, while the peeled volume model demonstrated the

Table 1
Twenty-seven extrinsic and intrinsic hand muscles that have been outlined and surface reconstructed.

Groups	Structures
Anterior compartment of forearm (7)	Flexor carpi radialis, Palmaris longus, Flexor carpi ulnaris, Flexor digitorum superficialis, Flexor digitorum profundus, Flexor pollicis longus, Pronator quadratus
Posterior compartment of forearm (9)	Extensor digitorum, Extensor digiti minimi, Extensor carpi ulnaris, Extensor carpi radialis brevis, Extensor carpi radialis longus, Abductor pollicis longus, Extensor pollicis brevis, Extensor pollicis longus, Extensor indicis
Thenar space (4)	Abductor pollicis brevis, Flexor pollicis brevis, Opponens pollicis, Adductor pollicis
Hypothenar space (3)	Abductor digiti minimi, Flexor digiti minimi brevis, Opponens digiti minimi
Midpalmar space (4)	Palmaris brevis, Lumbrical muscles, Dorsal interossei, Palmar interossei

(Number of structures).

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