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Serially Rotated Images of the Dissected Knee for Learning Knee Anatomy

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ABSTRACT The purpose of this study is to present the serially rotated images (SRIs) of the dissected knee for the production of educational software of knee anatomy. In order to achieve the purpose, the SRIs of dissected knee were generated as follows. An embalmed knee was serially dissected to make eight layers of the dissected knee. The knee in each layer was serially rotated at every five degree angle and photographed to obtain 72 SRIs. In every SRI, all anatomical structures were annotated. The knee was serially flexed to make additional SRIs. Similar procedures were performed with a fresh knee. The SRIs of knee, prepared in this study, will be used as sources of the software, which will be helpful in educating knee anatomy.

Key words : Serially rotated images, Dissection, Flexion, Rotation, Knee anatomy

INTRODUCTION

For the accurate diagnosis and treatment of the knee, stereoscopic anatomy of knee structures needs to be learned by both medical students and orthopedic surgeons alike. As the classical method, knee anatomy can be learned through hands-on dissection of the cadaver. However, the cadaver dissection provides neither comfort nor reproducibility.

Knee anatomy can be studied with virtual dissection of three-dimensional (3D) images, which are reconstructed through volume reconstruction of serially sectioned images of knee such as the Visible Human Project (Spitzer *et al*., 1996), Chinese Visible Human (Zhang *et al*., 2004), and Visible Korean Human (Park *et al*., 2005a, b; Park *et al*., 2006). Nevertheless, it is exceptionally complicated to virtually dissect the 3D images in layers and also to virtually flex the 3D images, due to the difficulty of each anatomical structure's segmentation and tissue transformation (Fig. 1).

Knee anatomy can be studied through observation of serially rotated images (SRIs) of a dissected knee. At Michigan Medical School (http://anatomy.med.umich.edu/ qtvr/ qtvr_movs.html), after dissecting an embalmed knee, the knee was serially rotated at every ten degree angle and photographed to obtain 36 SRIs; the knee was serially flexed at every ten degree angle and photographed to obtain additional SRIs; in total, 288 (=36×8) images were prepared (Fig. 2). The images can be browsed to assist the education of knee anatomy. Moreover, six knee structures (tibial collateral ligament, fibular collateral ligament, anterior cruciate ligament, posterior cruciate ligament, medial meniscus, lateral meniscus) in the images were annotated (Fig. 3). However, the images did not include the following images: images of fresh cadaver which are helpful in clinics; images of stepwise dissected knee which show much more knee structures; images at five degree angle which is suitable for stereoscopy of knee structures.

The purpose of this study is to present the SRIs of dissected knee for the production of educational software of knee anatomy.

MATERIALS AND METHODS

A right knee was amputated using a saw from an embalmed male cadaver in Stanford University; the knee was mounted on a plate, placed on a frame. Spongy bones of the tibia and fibula of the knee were drilled in appropriate thickness and depth to construct two canals, which were then washed out with alcohol. Two screws were inserted into the two canals

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Fig. 1. Virtual dissection of the 3D images of knee made of the Visible Human Project data.

Fig. 2. SRIs (left four) and serially flexed images (right four) of the dissected knee from Michigan Medical School.

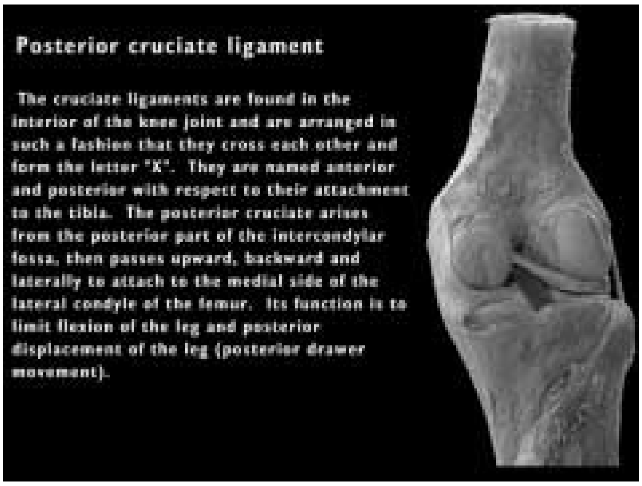

Fig. 3. Annotation and explanation of the tibial collateral ligament in the knee image from Michigan Medical School.

and tightly fixed with glue (Fig. 4A). Opposite ends of the screws were fixed on a plate equipped with circular protractor (Fig. 4B, C). Simultaneously, the rotating axis of the knee was considered. As a result, the knee was firmly mounted on the plate. The knee, mounted on the plate, was placed on a frame, which was designed to manually rotate the knee at every five degree angle with reference of the circular protractor and to manually flex the dissected knee at every regular angle using a thin thread.

A digital camera and an illuminator were installed for photographing the knee in the frame. Around the frame, the location and the direction of the illuminator (Elinchrom 1000) were decided and fixed to illuminate the knee appropriately with adequate amount of shadow. Simultaneously, room brightness was adjusted constantly using exposure meter. Photographic black velvet was used as background of the knee (Fig. 5A). The digital camera (Canon EOS D60; resolution, 3,072 × 2,048) was connected to the computer and the illuminator. The digital camera was controlled by the computer; photographing of the camera was synchronized with flashing of the illuminator. Shutter speed and aperture opening speed of the digital camera were adjusted to 1/250 and 22, respectively; resolution, bits depth, and file format were adjusted to 2,048 × 3,072, 24 bits color, and Joint Photographic Experts Group (JPEG), respectively (Fig. 5B). Location and direction of the digital camera were decided and fixed using a tripod (Fig. 5C).

The knee was rotated and photographed to obtain SRIs as the first layer. The knee was not yet dissected, to show skin

A B C

Fig. 4. Mounting of knee on the plate equipped (A) with circular protractor (B), which is placed on the frame (C).

A B C

Fig. 5. Illuminator, reflecting plate, photographic black velvet (A), digital camera, and personal computer (B), which are installed for photographing the knee in the frame (C).

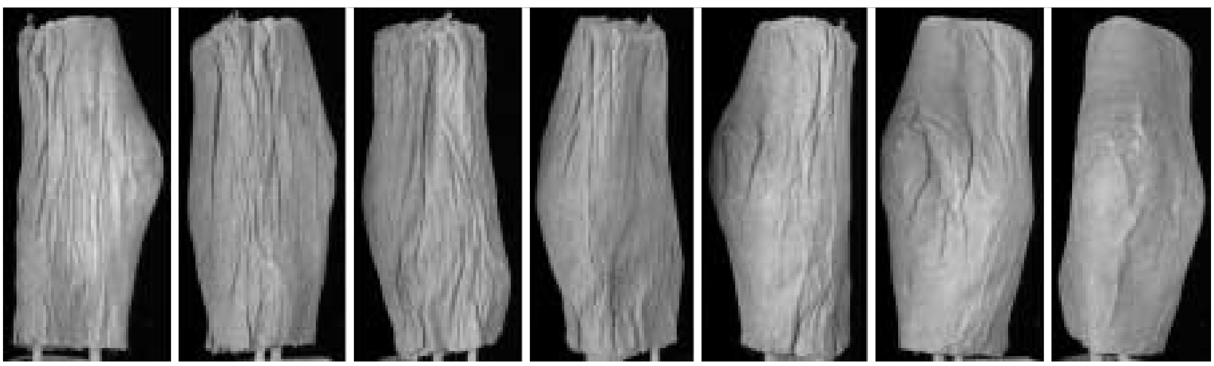

Fig. 6. SRIs of the knee with skin, which are the first layer.

only. The knee in the frame was serially rotated at every five degree angle and photographed until the knee was rotated one whole round to obtain 72 SRIs, which were then saved as JPEG files on the computer. The images were regarded as the

Fig. 7. Lateral view of the knee, which is serially dissected from the first layer to the eighth layer.

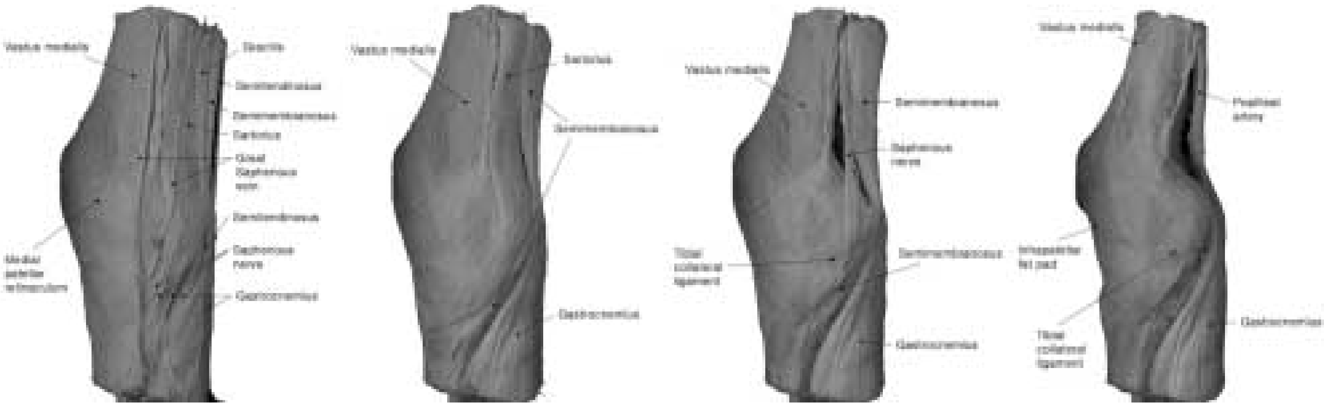

Fig. 8. Medial view of the dissected knee, in which anatomical structures are annotated.

Table 1. Features of SRIs of the embalmed and fresh knees

	Number of layers (Dissected knee+Flexed knee)	Total file size
Embalmed knee	12 (8+4)	1.0 GBytes
Fresh knee	18 (8+10)	1.8 GBytes

Number of the SRIs in a layer is 72.
Resolution, bits depth, file format, and file size of a SRI is 2,048 × 3,072, 24 bits color, JPEG, and 1.2 Mbytes, respectively.

first layer (Fig. 6).

The knee was serially dissected, rotated, and photographed to obtain SRIs, as second to eighth layers. The knee mounted on the plate was detached from the frame. After skinning the knee, superficial anatomical structures (iliotibial tract, lateral patellar retinaculum, medial patellar retinaculum, patellar ligament, long head of biceps femoris, crural fascia, fascia lata, gastrocnemius, gracilis, rectus femoris, sartorius, semimembranosus, semitendinosus, soleus, vastus medialis, common fibular nerve, lateral sural cutaneous nerve, medial sural cutaneous nerve, saphenous nerve, tibial nerve, great saphenous vein, popliteal vein, small saphenous vein) were dissected to be cleaned. The dissected knee, still mounted on the plate, was placed back in the frame, serially rotated at every five degree angle and photographed to obtain 72 SRIs, which were regarded as the second layer. These procedures were repeated until only joint structures (anterior cruciate ligament, fibular collateral ligament, interosseous membrane, lateral meniscus, medial meniscus, posterior cruciate ligament, tibial collateral ligament) and bones remained, whose images were regarded as the eighth layer. During the dissection, it was intended to identify each layer differently from neighboring layers in respect of the anatomical structures. As a result, 576 (=72 × 8) SRIs were prepared (Fig. 7, Table 1). Names of the anatomical structures in each layer were noted except the bones; 46 anatomical structures were categorized by joint, muscles, nerves, arteries, and veins (Table 2).

In the SRIs from the second layer to the eighth layer, anatomical structures were pointed and annotated (Fig. 8, Table 2).

The knee was flexed stepwise, serially rotated, and photographed to obtain SRIs of flexed knee. The totally dissected knee with only joint structures and bones were flexed stepwise at every 22.5 degree angle using a thin thread in the

Table 2. Anatomical structures of the embalmed knee in the 2nd to 8th layers

		2nd	3rd	4th	5th	6th	7th	8th
Joint	Anterior cruciate ligament						○	○
	Fibular collateral ligament			○	○	○	○	○
	Iliotibial tract	○						
	Infrapatellar fat pad				○			
	Interosseous membrane						○	○
	Lateral meniscus					○	○	○
	Lateral patellar retinaculum	○						
	Medial meniscus					○	○	○
	Medial patellar retinaculum	○						
	Patellar ligament	○	○	○				
	Posterior cruciate ligament							○
	Tibial collateral ligament			○	○	○	○	○
Muscles	Biceps femoris (long head)	○	○					
	Biceps femoris (short head)			○				
	Crural fascia	○						
	Extensor digitorum longus		○					
	Fascia lata	○						
	Fibularis longus		○					
	Gastrocnemius	○	○	○	○			
	Gracilis	○						
	Plantaris					○		
	Popliteus					○	○	
	Rectus femoris	○	○					
	Sartorius	○	○					
	Semimembranosus	○	○	○				
	Semitendinosus	○						
	Soleus	○	○	○	○	○		
	Tibialis anterior		○	○				
	Vastus intermedius			○	○	○		
	Vastus lateralis		○	○				
	Vastus medialis	○	○	○				
Nerves	Common fibular nerve	○	○	○	○			
	Deep fibular nerve			○	○			
	Lateral sural cutaneous nerve	○	○	○	○			
	Medial sural cutaneous nerve	○						
	Saphenous nerve	○		○				
	Sciatic nerve			○	○	○		
	Superficial fibular nerve			○	○			
	Tibial nerve	○	○	○	○	○		
Arteries	Anterior tibial artery			○	○	○	○	
	Fibular artery						○	
	Popliteal artery		○	○	○	○	○	
	Posterior tibial artery						○	
Veins	Great saphenous vein	○						
	Popliteal vein	○	○	○				
	Small saphenous vein	○	○	○				

The 1st layer shows only the skin of the knee.
The 9th to 12th layers show knee flexion.

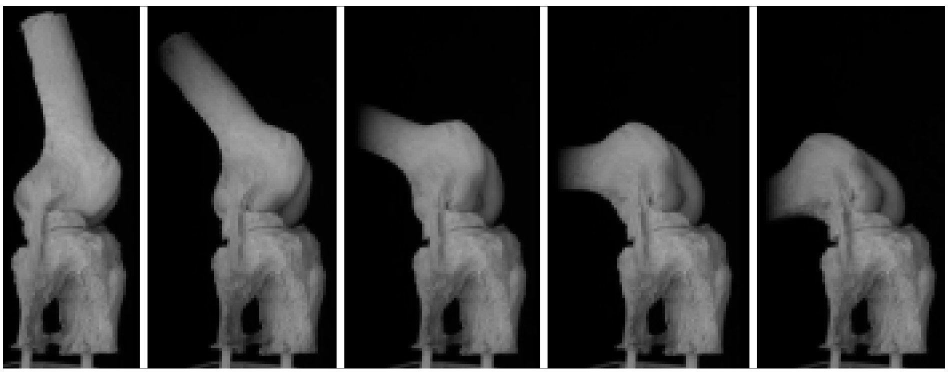

Fig. 9. Lateral view of the knee, which is serially flexed from the eighth layer to the twelfth layer.

Table 3. Anatomical structures of the fresh knee in the 2nd to 8th layers

		2nd	3rd	4th	5th	6th	7th	8th
Joint	Anterior cruciate ligament							○
	Fibular collateral ligament					○	○	○
	Iliotibial tract		○					
	Infrapatellar fat pad				○	○	○	
	Interosseous membrane							○
	Lateral meniscus						○	○
	Lateral patellar retinaculum		○	○				
	Medial meniscus						○	○
	Medial patellar retinaculum		○	○				
	Patellar ligament		○	○	○	○	○	
	Posterior cruciate ligament							○
	Tibial collateral ligament					○	○	○
Muscles	Adductor magnus				○	○	○	
	Biceps femoris		○	○	○			
	Crural fascia	○	○					
	Extensor digitorum longus			○	○			
	Fibularis longus			○				
	Gastrocnemius		○	○	○			
	Gracilis		○	○	○			
	Popliteus						○	
	Rectus femoris		○	○				
	Sartorius		○	○				
	Semimembranosus		○	○	○			
	Semitendinosus		○	○				
	Soleus		○	○	○	○		
	Tibialis anterior			○	○	○		
	Vastus intermedius				○	○	○	
	Vastus lateralis		○	○	○	○		
	Vastus medialis		○	○	○	○		
Nerves	Common fibular nerve			○	○	○	○	
	Deep fibular nerve				○	○	○	
	Superficial fibular nerve						○	
	Tibial nerve			○	○	○	○	
Arteries	Anterior tibial artery						○	
	Popliteal artery					○	○	
	Posterior tibial artery						○	
Veins	Great saphenous vein	○						
	Popliteal vein					○		
	Small saphenous vein	○	○					

The 1st layer shows only the skin of the knee.
The 9th to 18th layers show knee flexion.

frame. The serially flexed knee was serially rotated and photographed to obtain additional SRIs of the flexed knee, which were regarded as four more (the ninth to twelfth) layers. The number of the additional SRIs were 288 (=72×4) images (Fig. 9, Table 1).

Similar procedures were performed with fresh knee of male cavader, which was frozen in a freezer, to create other SRIs. The procedures for the fresh knee were different from those for the embalmed knee, as follows. Dissection of the knee had to be finished during a couple of days after melting the knee in room temperature. The SRIs showed 39 different anatomical structures (Table 3). The knee was flexed at every nine degree angle; producing 10 more layers, from the ninth layer to the eighteenth layer (Fig. 10, Table 1).

RESULTS

Eight-hundred sixty-four (=72×12) SRIs of the embalmed knee and 1,296 (=72×18) SRIs of the fresh knee were prepared (Figs. 6-10) . The file size of a SRI (resolution, 2,048 ×3,072; bits depth, 24 bits color; file format, JPEG) was 1.2 Mbytes, so that total file size of the SRIs of the embalmed knee reached 1.0 GBytes and that of the fresh knee was 1.8 GBytes (Table 1).

The SRIs were aligned thanks to the proper location of every dissected knee in the frame, correct rotation of the knee, and the precise location of the digital camera. It was verified by alignment of the images in the different layers. In addition,

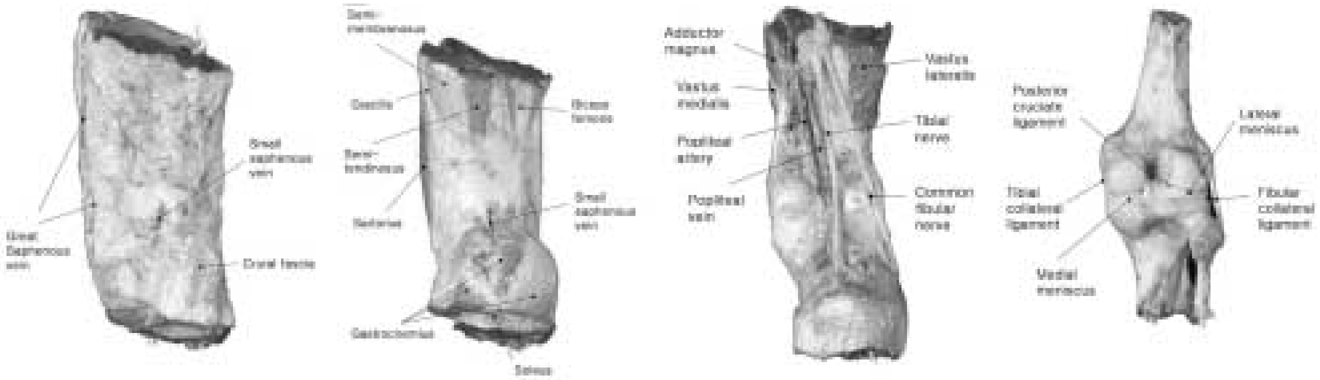

Fig. 10. Medial view of the dissected knee, in which anatomical structures are annotated.

brightness of all SRIs was constant thanks to the fixed illumination (Figs. 4, 5).

The SRIs of the embalmed knee showed well-defined anatomical structures, which were clearly dissected (Figs. 7, 8). In contrast, the SRIs of the fresh knee showed realistic anatomical structures, which had a color identical to the living body (Fig. 10). Forty-six anatomical structures in the SRIs of the embalmed knee and 39 SRIs of the fresh knee could be easily identified thanks to the annotation (Figs. 8, 10). Additional SRIs of the flexed knee showed movement of the ligaments and articular menisci (Fig. 9).

DISCUSSION

The SRIs of dissected knee, prepared in this study, will be used as sources of the software, which will be helpful to anatomy education for medical student and to study clinical anatomy for medical doctor in the following aspects. First, they could observe the virtual embalmed knee and fresh knee because the embalmed and fresh knee was photographed using a digital camera with high resolution (Fig. 5). Second, they could virtually dissect the knee as he would dissect it in real life, since eight layers of images including different dissection levels were prepared (Figs. 6, 7, 10). Third, they could easily comprehend nature movement of knee including ligaments and articular meniscus as well as stereoscopic shape because the images were made to include flexion and rotation (Figs. 6, 7, 9). Fourth, they could learn by themselves because names of structures were annotated (Figs. 8, 10).

In order to create useful SRIs in the next study, the SRIs need to be made with revisions as follows. First, it is necessary to generate images of other body regions. At Michigan University, images of other body regions were already made but the quality of images was poor; for example, resolution of the images was low. Second, it is essential to create more layers of images than 8 layers and rotate at a narrower angle than five degrees. Third, it is obligatory to explain the annotated structures as the researchers at Michigan University did (Figs. 2, 3). In this study, only names of structures were annotated (Figs. 8, 10). Consequently, this annotation was not sufficient for self-learning. Fourth, it is crucial to display MR and CT images corresponding to the serially sectioned images of this study. Fifth, it is necessary to store the images in TIFF format. If a 3D image is reconstructed using JPEG format, as it has been done in this study, the quality of the 3D image will be poor. Sixth, it is required to segment the SRIs in detail. At Michigan University, the images were already segmented but the number of segmented structures was not adequate.

At Stanford University, a remote stereo viewer (RSV), through which the hand of the cadaver could be virtually dissected by internet, was constructed. We have collaborated with researchers at Stanford University in creating virtual anatomy software such as RSV (Dev *et al.*, 2006). Therefore, virtual anatomy software including new RSV with this study will be constructed in the near future and prove helpful in self-learning the knee anatomy.

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무릎 해부학을 익히기 위한 무릎의 연속돌림영상

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초 록 : 이 연구의 목적은 무릎의 연속돌림영상을 만들어서 무릎 해부학을 익히는 데 도움주는 것이다. 이를 위해서 고정한 시신의 무릎을 여덟 층으로 해부한 다음에 각 층을 5도 간격으로 돌리면서 사진 찍었다. 더불어 무릎관절을 조금씩 굽히면서 사진 찍었다. 각 영상마다 해부구조물의 이름을 붙였다. 이 결과로 한 층에 72개, 총 864개의 연속돌림영상을 만들었다. 같은 방법으로 고정하지 않은 시신의 무릎을 해부한 다음에 돌리면서 사진찍었다. 이 결과로 한 층에 72개, 총 1,296개의 연속돌림영상을 만들었다. 이 연구에서 마련한 무릎연속돌림영상은 무릎 해부학을 익히는 소프트웨어를 만드는 데 도움될 것이다.

찾아보기 낱말 : 연속돌림영상, 해부, 굽힘, 돌림, 무릎 해부학