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Comparative Evaluation of Anatomic Structures in *Regio manus* and *Regio pedis* on Computed Tomography Images and Plastinated Cross-Sections of Horse

Evaluación Comparativa de Estructuras Anatómicas en *Regio Manus* y *1* en Imágenes de Tomografía Computarizada y Cortes Transversales Plastinados de Caballos

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SUMMARY: Movement analysis of horses is closely related to the bone, joint and muscle composition. Equine foot is quiet important not only for veterinarians, but also for farmers and horseshoer. In this study, it is aimed to evaluate and compare the anatomical structures of equine foot obtained from computed tomography images and S10B silicone plastinated sections of horse and 3 dimensional images of related structures as well. Four adult horses were used in this study. Computed tomography images were acquired in a proper position for equine feet. Then S10B silicone plastination was performed for the same specimens. Plastinates were sliced into 1 cm sections, corresponding to the computed tomography images. The sections obtained from silicone plastination were found to be compatible with computed tomography images. It was seen that osseous structures and tendons were clearly identified on computed tomography images. It was observed that the shrinkage on the osseous tissues was very limited. It was thought that the proportional differences between the plastinated specimens and computed tomography images were related with the fixation process. The specimens plastinated with S10B silicone polymer was determined to be closer to natural colour when compared to the standard polymers. Therefore it was found to be more useful. It is considered that plastinates can be effectively used in veterinary orthopaedics and radiology trainings as well as in veterinary anatomy education.

KEY WORDS: Computed tomography, foot, horse, plastination, 3D reconstruction.

INTRODUCTION

Movement analyses of horses are closely related to the bone, joint and muscle composition and additionally shape, angle and length ratios of the related structures (Kane *et al*., 1998). Because of the fact that this region has a complex anatomy, it needs to be studied in detail both in anatomy education and clinical examination. In recent years, detailed examination of complex anatomical structures has been performed by various imaging systems such as radiography, computed tomography (CT) and magnetic resonance imaging (MRI) (Vanderperren *et al*., 2008; Raes *et al*., 2011). Although more detailed data are available for soft tissues with the MRI, CT is become popular in horse clinics for evaluation of bony structures and soft tissues (Tomlinson *et al*., 2003; Claerhoudt *et al*., 2014). However, in order to understand the complex anatomy of CT images, cross-sectional anatomy education and knowledge must be well conveyed (Raji *et al*., 2008). Computed tomography is convenient for evaluating the osseous anatomic structures without superimposition. It is quite effective to diagnose the diseases related with bone pathologies as well. The use of CT images, 3 dimensional (3D) reconstruction models and better anatomic orientation can be easily evaluated during multi-plane reformatting (Tomlinson *et al*.; Raes *et al*.; Claerhoudt *et al*.).

Beside the active use of radiological anatomy, professional models and computer-based learning are also the educational tools used in anatomy courses (Estai & Bunt, 2016). Plastination is the most important long term preservation technique for anatomy teaching in recent years (Latorre & Rodriguez, 2007). Anatomists prefer to use

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plastinated specimens because they are odourless, practical, stored for many years and prepared in various forms (Latorre & Rodriguez; Estai & Bunt). It can be used not only for whole body parts or organs but also for sectional anatomy of various regions. In addition to that, a concerted use of macroscopic cross sections of plastinated specimens and cross sectional images of computed tomography can provide beneficial information for clinical anatomy and anatomy education (Latorre *et al*., 2003; Riederer, 2014).

The objectives of this study were: 1) to evaluate and compare the anatomical structures of equine foot obtained from computed tomography images and S10B silicone plastinated sections and 2) to create 3D reconstructed images of specified regions including bones and surrounding tissues.

MATERIAL AND METHOD

The feet of four adult horses, died from various causes that didn't affect the musculoskeletal system, were scanned and then plastinated in this study. The study was approved by Ankara University Animal Experiments Local Ethics Committee (Decision no.: 2017-13-104).

The feet were detached from the midpoints of metacarpal and metatarsal joints with an electric hand saw (Bosch, PFZ 550E, Scintilla, Switzerland). Computed tomography imaging was performed 1 hour after the feet were cut. The CT scans were performed with a single detector spiral CT scanner (General Electric, GE Medical Systems, Milwaukee, WI brand, 2119734-2 model) in which the feet were placed in the gantry with the longitudinal axis of the foot oriented parallel to the CT table. Slice thickness was 1 mm from proximal to distal direction. The scanning parameters were recorded as follows; 120 kV, 190 mAs, window level 1180 HU, window width 2350 HU and 512 ¥ 512 pixel matrix. 3D reconstructed images of entire feet were created using 3D slicer (3D slicer, 4.7.0 version, GitHub, San Francisco) and Horos (GNU Lesser General Public License, 3.0 version) software through DICOM files. 3 dimensional images were obtained by volume rendering on indicated window level. After the CT imaging and 3D reconstruction were completed, S10B silicone plastination was performed to this specimens. Plastination process was completed in four different stages. These stages were fixation stage with 4 % formalin, dehydration stage with three consecutively 100 % acetone bath (Birpa Kimya, Ankara, Turkey), forced impregnation stage with S10B reddish polymer and S3 catalyst material (Biodur Products, Heidelberg, Germany), gas curing stage with S6 chemical (Biodur Products, Heidelberg, Germany), respectively. Afterwards, plastinates were cut into 1 cm thickness sagittal and transversal planes with an electric bandsaw (Electric band saw, Mutas¸, Turkey). Finally, cross sections of plastinates were photographed in high resolution and compared with CT images on the computer.

RESULTS

Five CT images in transversal plane (Fig. 1) were selected for matching up with their corresponding plastinated sections. Plastinated and CT sections either demonstrated anatomical structures in detail. In the selected CT images with WW = 2350 HU, WL = 1180 HU settings and corresponding sections of the plastinated specimen; the metacarpal bone III and its sagittal ridge, the proximal sesamoid bones, proximal phalanx, middle phalanx, distal phalanx, distal sesamoid bone, branches of the suspensory ligament, collateral ligament, intersesamoidean ligament, deep digital flexor tendon, superficial digital flexor tendon, common and long digital extensor tendons were well determined. It was observed that osseous structures and tendons were identified easier than ligaments on CT images. Osseous structures were determined hyperdense. However tendons and ligaments demonstrated different shades of grey colour. Both of the transversal and sagittal CT images were convenient to identify the extensor and flexor tendons but the extension of the tendons were identified much better in sagittal images. It was seen that superficial surface of the deep digital flexor tendon with ellipsoidal shape was surrounded by the superficial digital flexor tendon. The suspensory ligament was circular at the lateral and medial borders of the metacarpal bone. When it fused to the proximal sesamoid bones, it became more trapezoidal shape. The intersesamoidean ligament that attaches proximal sesamoidean bones could not clearly defined. The other ligament and tendons such as the metacarpointersesamoidean ligament and lateral digital extensor tendon could not clearly identified either.

It was seen that the plastinated cross sections were found to be compatible with the corresponding CT images and these sections could be useful for education in veterinary anatomy. Matching between plastinates and CT images were efficiently applied. It was observed that the shrinkage on the osseous tissues and tendons were very limited. The colour differences of the tissues were clearly recognized plastinated cross sections. Bony structures, tendons and surrounding tissues were easily distinguished from each other in plastinated specimens. The images obtained from the transversal plastinated sections were found to contain more detail than the sagittal sections.

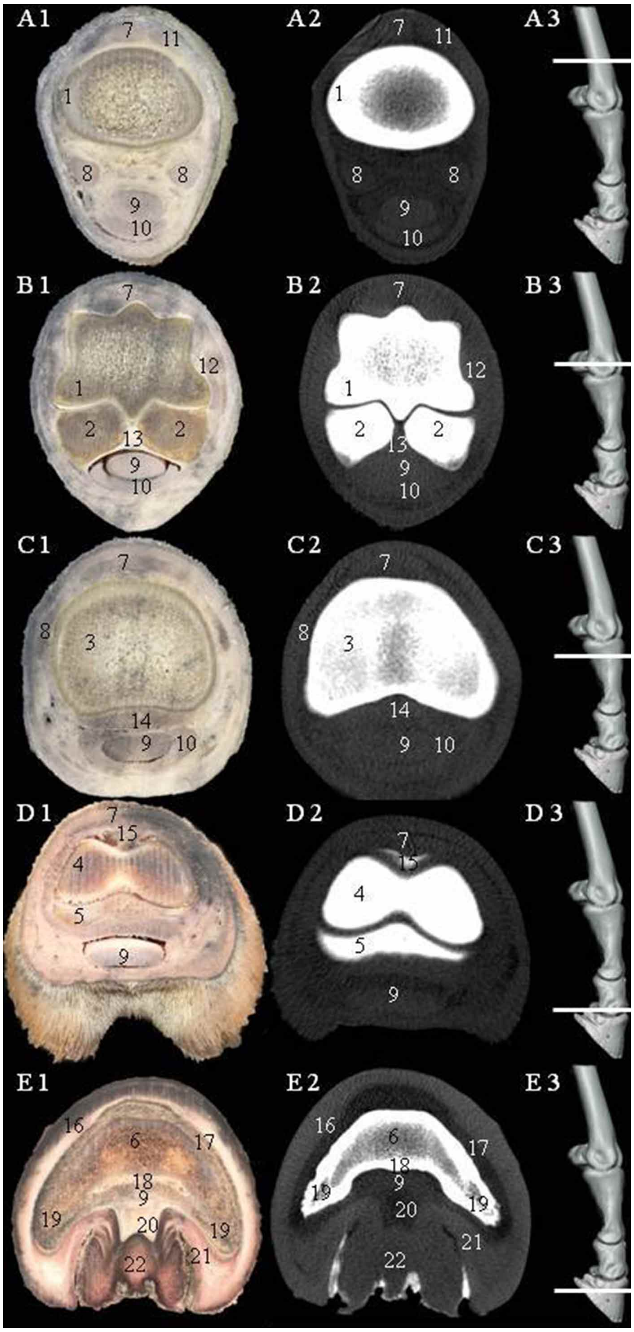

Fig. 1. Photographic views of transversal plastinated (A1 - E1) and transversal CT (A2 - E2) images with anatomical structures. Selected planes were shown on 3D reconstruction model (A3 – E3). 1. Metatarsal bone; 2. Proximal sesamoid bone; 3. Proximal phalanx; 4. Middle phalanx; 5. Distal sesamoid bone; 6. Distal phalanx; 7. Long digital extensor tendon; 8. Suspensory ligament; 9. Deep digital flexor tendon; 10. Superficial digital flexor tendon; 11. Lateral digital extensor tendon; 12. Collateral ligament of metatarsophalangeal joint; 13. Intersesamoidean ligament; 14. Sesamoidean ligaments; 15. Extensor process; 16. Hoof wall; 17. Corium parietis; 18. Flexor surface of distal phalanx; 19. Plantar process of distal phalanx; 20. Cuneal part of digital cushion; 21. Sole; 22. Frog.

Two 3D reconstructed models (Figs. 2 and 3) were chosen to illustrate the anatomical structures. It was determined that the 3D models reflect the original anatomic positions. In addition to that, anatomical details for the 3D models were quite satisfying.

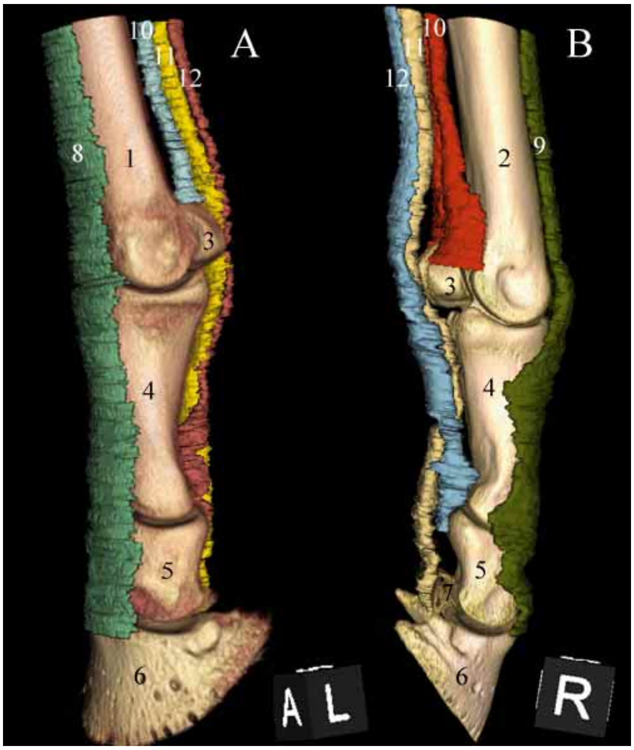

Fig. 2. Photographs of 3D model of forelimb (A) and hindlimb (B) with anatomical structures by using 3D slicer software. 1. Metacarpal bone; 2. Metatarsal bone; 3. Proximal sesamoid bone; 4. Proximal phalanx; 5. Middle phalanx; 6. Distal phalanx; 7. Distal sesamoid bone; 8. Common digital extensor tendon; 9. Long digital extensor tendon; 10. Suspensory ligament; 11. Deep digital flexor tendon; 12. Superficial digital flexor tendon.

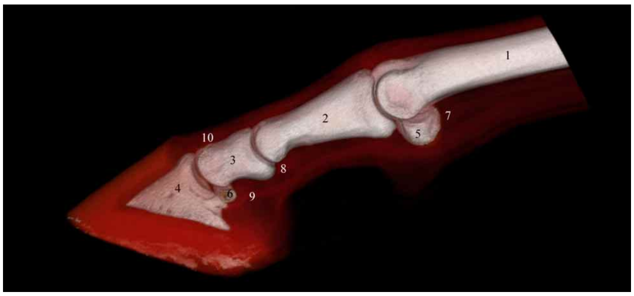

Fig. 3. Photograph of 3D model with anatomical structures by using Horos software. 1. Metacarpal bone; 2. Proximal phalanx; 3. Middle phalanx; 4. Distal phalanx; 5. Proximal sesamoid bone; 6. Distal sesamoid bone; 7. Suspensory ligament; 8. Superficial digital flexor tendon; 9. Deep digital flexor tendon; 10. Common digital extensor tendon.

DISCUSSION

Researches in veterinary medicine have developed in recent years due to the possibilities provided by technology. This development has actualized with the combination of technology and science such as plastination (Latorre *et al*.; Latorre & Rodriguez), imaging systems (Tomlinson *et al*.; Raji *et al*.; Claerhoudt *et al*.), 3D imaging and modelling (Martinelli *et al*., 1997; Raes *et al*.; Preece *et al*., 2013). This study was performed to provide reference for CT imaging and plastinated specimen anatomy of the normal equine foot with cross section images of various plane and 3D reconstruction images. These images were composed by 1 mm thick slices with single detector CT scanner in three planes, 1 cm thick slices of S10B silicone plastination and 3D images of rendering CT images.

As stated in previous studies, CT is known to be the best imaging system that can demonstrate the detail of osseous structures (Vanderperren *et al*.; Raes *et al*.; Claerhoudt *et al*.). This information has been supported by our study with the cross section and 3D images obtained from osseous structures. Metacarpal/metatarsal bone, proximal sesamoid bones, proximal phalanx, middle phalanx, distal phalanx, distal sesamoid bone, corium and hoof wall are well determined in CT images. In addition, 3D images are considered to make more understandable the complex anatomical structures during anatomy education (Preece *et al*.; Estai & Bunt). It is thought that the 3D images obtained from this study will support to understand the relationship of the bones, tendons and surrounding tissues with each other.

The difficulty of finding continuous cadavers for anatomy education due to ethical factors is a common problem. It is known that cadavers cannot be used for a long time (Riederer). Dissections of cadavers are also accepted as outdated, time consuming and hazardous but gold standard for anatomy teaching. For these reasons less time consuming and up to date techniques, such as plastination or computer based learning, have been started to use in anatomy education (Estai & Bunt). Plastination is a new technique that overcomes such difficult problems. Especially it is stated that S10 technique is suitable for large and well dissected body parts (Latorre *et al*.; Riederer). It is thought that this study is contributed to anatomy education by preserving the original form of cadavers with plastinated specimens. It is observed that the specimens were preserved in almost the natural tissue colour in S10B silicone plastination due to its pigmented form. It is also planned to support clinical anatomy education through CT images corresponding with sections of plastinated specimens.

It is known that structures of soft tissue can be seen with CT images (Raji *et al*.; Vanderperren *et al*.; Raes *et al*.; Claerhoudt *et al*.). Although this information is supported by this study, the inadequacy of CT has been noticed in complex anatomic regions. The common digital extensor tendon, the long digital extensor tendon, the deep digital flexor tendon, the superficial digital flexor tendon and the suspensory ligament are well defined in CT images. The borders of the tendon and ligaments such as the collateral ligaments of metacarpophalangeal joint have not been clearly identified due to their close relationship and position. It is stated that MRI can be effectively used for imaging soft tissue in studies (Martinelli *et al*.; Claerhoudt *et al*.). It has been thought that MRI can be preferred to view complex structures of soft tissues.

The knowledge of the 3D anatomy will make the procedure safer, easier and more accurate in surgical and orthopaedic operations. 3D reconstruction is performed by using CT and MRI serial cross section images. It is known that 3D images of soft and osseous tissues acquired from plastinated specimens can be formed. These images can be used for measurement, biometric researches, experimental studies, evaluating the structure from different angles and providing useful information for operations (Latorre *et al*.; Latorre & Rodriguez; Raji *et al*.). Bones and tendons are evaluated from different angles with 3D reconstruction in this study. Although the rendering of the CT images took a bit long time, it showed how the tendons travelled along the desired region. It will be beneficial teaching model for students for using in anatomy and orthopedy education.

In conclusion, it was detected that the S10B silicone polymer was convenient to provide natural colour when compared to the standard polymers. It is considered that plastinated specimens and 3D models can be effectively used in veterinary orthopaedics and radiology education as well as veterinary anatomy. A combined use of serial section images of plastinated specimen, different aspect of the CT images and 3D reconstruction models from the same specimen allowed a precise evaluation of anatomic structures on the organ.

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RESUMEN: El análisis del movimiento de los caballos está estrechamente relacionado con la composición ósea, articular y muscular. El pie equino es muy importante no solo para los veterinarios, sino también para los agricultores y herradores. El objetivo de este trabajo consistió en evaluar y comparar las estructuras anatómicas del pie equino obtenidas a partir de imágenes de tomografía computarizada y secciones plastinadas con silicona S10B y también con imágenes tridimensionales de estructuras relacionadas. Cuatro caballos adultos fueron utilizados en este estudio. Las imágenes de tomografía computarizada se adquirieron en una posición adecuada para los pies equinos. Luego se realizó plastinación con silicona S10B para las mismas muestras. Los plastinados se cortaron en secciones de 1 cm, correspondientes a las imágenes de tomografía computada. Las secciones obtenidas de plastinación con silicona fueron compatibles con las imágenes de tomografía computarizada. Se observó que las estructuras óseas y los tendones estaban claramente identificados en las imágenes de tomografía computarizada. Se observó que la contracción de los tejidos óseos era muy limitada. Se pensó que las diferencias proporcionales entre las muestras plastinadas y las imágenes de tomografía computada estaban relacionadas con el proceso de fijación. Se determinó que las muestras plastinadas con polímero de silicona S10B se presentaron con un color más cercano al natural en comparación con los polímeros estándar. Por lo tanto, se encontró que fue más útil. Se considera que los plastinados se pueden utilizar eficazmente en ortopedia veterinaria y capacitación en radiología, así como en educación en anatomía veterinaria.

PALABRAS CLAVE: Tomografía computarizada; Pie; Caballo; Plastinación; Reconstrucción 3D.

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