Ankara Univ Vet Fak Derg, **69**, 419-424, 2022
DOI: 10.33988/auvfd.884974

Evaluation of the compatibility between corrosion casts and 3D reconstruction of pig head arterial system on cone beam computed tomography

Nikolay TSANDEV[1,a], Caner BAKICI[2,b,✉], Angel VODENICHAROV[1,c]

[1]Department of Veterinary Anatomy, Histology and Embryology, Faculty of Veterinary Medicine, Trakia University, Stara Zagora, Bulgaria; [2]Department of Anatomy, Faculty of Veterinary Medicine, Ankara University, Ankara, Türkiye
[a]ORCID: 0000-0003-1960-2987; [b]ORCID: 0000-0003-2413-3142; [c]ORCID: 0000-0001-6094-7800

✉Corresponding Author: vetcanerbakici@gmail.com
Received date: 23.02.2021 - Accepted date: 21.08.2021

Abstract: This study aimed to compare the corrosion cast models of the porcine head arterial system with three-dimensional (3D) reconstructions using cone beam computed tomography (CBCT) of these cast models. Six heads from sows were simultaneously injected through both carotid arteries with Duracryl Plus for corrosion cast technique and an additional head, also from another one sow head, was filled with saturated lead tetroxide (Pb_3O_4) in a 10% hot water solution (40°C) of gelatin for CBCT study. Two-dimensional (2D) images were stored in Digital Imaging and Communications in Medicine (DICOM). Subsequently, segmentation and post-processing of these images were performed by using various software programs. The 3D models were found to be compatible with the corrosion cast models. It was observed that osseous structures and arteries were clearly identified on CBCT images. Specimen scan, segmentation, and post segmentation had a duration of 10-15 minutes, 4 hours, and 15 minutes, respectively. The internal carotid artery, external carotid artery, and its main branches were seen well on 3D models. In conclusion, it is considered that 3D models and images can be effectively used in anatomy education, radiological evaluations, pathological and variational investigations.
Keywords: Artery, cone beam computed tomography, corrosion cast, pig, three-dimensional reconstruction.

Konik ışınlı bilgisayarlı tomografide domuz kafa atardamar sisteminin üç boyutlu rekonstrüksiyon ile korozyon kast arasındaki uyumluluğun değerlendirilmesi

Özet: Bu çalışma, domuz kafa atardamar sisteminin korozyon kast modelleri ile bu modellerin konik ışınlı bilgisayarlı tomografisi (KIBT) kullanarak üç boyutlu (3B) rekonstrüksiyonlarının karşılaştırması amaçlanmıştır. Dişi domuzlara ait altı baş, aynı anda her iki şahdamarından, korozyon kast tekniği için Duracryl Plus enjekte edildi ve ayrıca bir başka dişi domuza ait bir baş, KIBT çalışması için %10 jelatinli sıcak su çözeltisi (40°C) içinde doymuş kurşun tetroksit (Pb_3O_4) ile dolduruldu. İki boyutlu (2B) görüntüler Tıpta Dijital Görüntüleme ve İletişim (DICOM) formatında saklandı. Daha sonra bu görüntülerin segmentasyonu ve son işlemleri çeşitli yazılım programları kullanılarak gerçekleştirildi. 3B modellerin, korozyon kast modelleriyle uyumlu olduğu görüldü. KIBT görüntülerinde kemik yapılar ve atardamarlar net olarak belirlendi. Örnek görüntüleme, segmentasyon ve segmentasyon sonrası işlemleri sırasıyla 10-15 dakika, 4 saat ve 15 dakika sürdü. İç karotis arter ile dış karotis arter ve ana dalları 3B modellerde iyi görüldü. Sonuç olarak anatomi eğitiminde, radyolojik değerlendirmelerde, patolojik ve çeşitli incelemelerde 3 boyutlu model ve görüntülerin etkin bir şekilde kullanılabileceği düşünülmektedir.
Anahtar sözcükler: Atardamar, domuz, konik ışınlı bilgisayarlı tomografi, korozyon kast, üç boyutlu rekonstrüksiyon.

Introduction

Recently studies have examining the vascular component of the head region of different animal species by using the corrosion cast technique (1, 19). This technique is used to visualize hollow or virtual anatomical spaces. The cavity is filled with a liquid or at least malleable substance, that is subsequently allowed to solidify, after which the surrounding tissues are removed by biological, enzymatic, or chemical maceration (4). When the morphology of the vascular system is examined with this technique, accurate diagnosis and follow-up of the disease are performed, as well as surgical planning and evaluation are possible. In addition, this technique is beneficial for both students and researchers in anatomy education, research, and clinical applications (5, 6, 18). However, its application is limited due to the application difficulties and repeatability problems. (9, 11, 12). For this reason, it is considered that the models obtained by the corrosion casting technique can be used in anatomy education by using a different method.

The adversities encountered in the corrosion casting technique can be prevented by using three-dimensional (3D) reconstruction models of cross-sectional images obtained using imaging systems (6, 11). It is necessary to scan the whole structure by one of the imaging systems (Magnetic resonance imaging, computed tomography, or micro-computed tomography) to obtain two-dimensional (2D) cross-sectional images of the structure, and combine these images by using different programs to create 3D models (6, 14, 16). Although the general anatomy of the vessels in the porcine head is known, there are no studies in which the techniques of corrosion casting and modeling with 3D reconstruction are applied.

Therefore, it was aimed to investigate the head arteries of porcine (*Sus scrofa domestica*) with 3D reconstructions models from cone beam computed tomography (CBCT) images and evaluate the compatibility with corresponding corrosion casting specimens.

Materials and Methods

Seven mature sow heads were obtained immediately after the slaughtering of animals (Six months old, 95 – 105 kg body weight) for meat consumption in a licensed abattoir (Han Asparouhovo, Stara Zagora, Bulgaria) in accordance with the Bulgarian respective legislation. The head arterial system was washed with distilled water through the common carotid arteries approximately twenty hours after the death until leakage of the residual blood via jugular veins for avoiding obstruction in downstream channels by blood clots (4). Subsequently, two syringes were mounted on both carotid arteries of six heads for simultaneous introduction of 100 ml of Duracryl Plus (Spofa Dental, Czech Republic) solution (50 g cold polymerizing mixture + 150 ml methacrylate) using a special device constructed by us for such purposes (Figure 1). After that, the filled specimens were left at room temperature for 24 hours to complete the resin's polymerization. Then the heads were placed into 5% Potassium hydroxide for 10 days at 45^{0}C for removing the soft tissue. Finally, the corrosion specimens were washed with slow running water with some detergent to removing the remaining fat. One additional head was injected in the same way with a saturated solution of 120 g lead tetroxide (Pb_3O_4) in 100 ml 10% gelatin in hot water (40^{0}C).

Following injection, specimens were scanned with the CBCT at the Trakia University Faculty of Veterinary Medicine in Stara Zagora, on a Fidex I (Fidex, Animage LLC, California, USA) which is a unique three-modality diagnostic imaging system (Figure 2a, Figure 2b and Figure 2c). Scan parameters for all specimens were 0.46 mm slice thickness, 110 kV and 150 mA, field of view 23 cm diameter, and total scanning time approximately 15 minutes. After the scanning process was performed all images were taken and transferred to the high-quality computer allowing the segmentation process. 2D images were uploaded to the 3D Slicer software program (3D slicer, 4.11.0 version, GitHub, San Francisco, USA). The 3D reconstruction models were segmented and created through all levels of the coronal, transversal, and sagittal cross-sections. During the segmentation process, the head skeleton and arteries were rendered in every section based on distinctive grey-scale values to separate the different tissues (Figure 2d). After the head skeleton and arteries were manually segmented, the 3D models were created one by one (8). Subsequently, the post-segmentation process was performed on the 3D digital models with Meshmixer software (Autodesk Inc., San Francisco, version 3.5). The final 3D models of the head skeleton and the arteries were achieved after corrections were applied (Figure 2e). The terms used in the descriptions below are from the Nomina Anatomica Veterinaria (15).

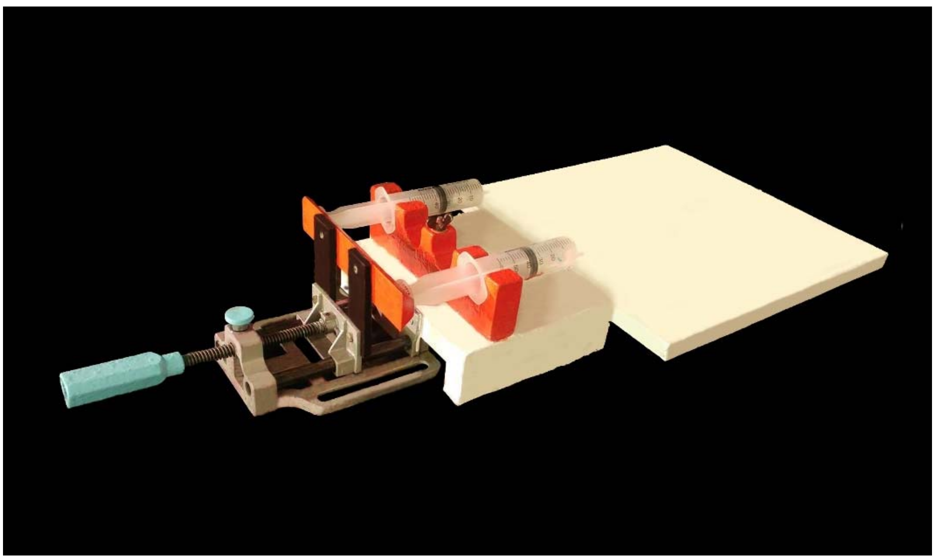

Figure 1. The device designed to fill the arteries of the samples simultaneously.

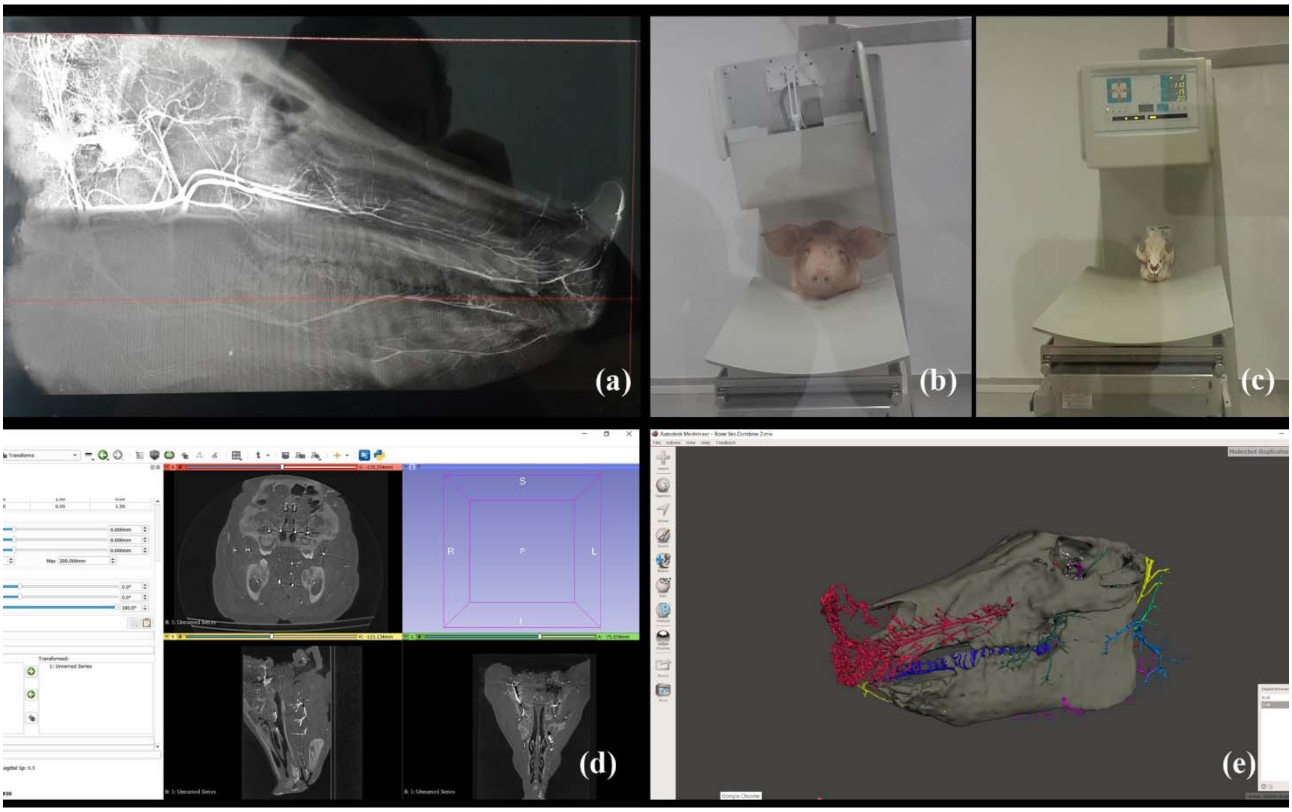

Figure 2. Stages of three-dimensional reconstruction of the specimens.
(a) Control for positioning of the corrosion cast specimens by radiography, (b) and (c) Scanning stage with cone-beam computed tomography of different corrosion casts, (d) Segmentation stage of 3D reconstruction models from different cross-sections, (e) Post-segmentation stage of the 3D models.

Results

It was seen that osseous structures and arteries could be well identified on CBCT images on both gelatin and the Duracryl corrosion casting specimens (Figure 2d, Figure 3b and Figure 3d). The combination of corrosion casting and CBCT scanning results in a visible arterial circulatory system that can be well separated from bone tissue (Figure 3). Specimen scanning, segmentation, and post segmentation had a duration of 10-15 minutes, 4 hours, and 15 minutes, respectively. Using these procedures, the 3D models of these anatomical casts of the vessels were displayed (Figure 3b and 3d) and it was seen that these models allow even better visualization of the morphology of the arterial circulatory system. The 3D model of the gelatin-filled cast (Figure 3d) and the Duracryl corrosion cast are shown in Figures 3d and 3b. It should be noted that gelatin gave better contrast on CBCT.

Almost all of the cranial head arteries, including branches of the internal carotid artery and external carotid artery were well visible on the 3D models of gelatin specimen. These arteries can be seen in Figure 4. It was also clearly seen that the right and left lingual arteries were anastomosed at the tip of the tongue (Figure 4, arrow). The 3D models were found to be compatible with the corrosion cast models. However, it was observed that the arteries were seen much better in gelatin specimens than the Duracryl corrosion cast specimens (Figure 3). Two different models of the cranial head arteries were given in Figures 3b and 3d.

Discussion and Conclusion

In literature, there are studies on the cranial head vessels of different animal species visualized by various chemicals and techniques that mostly concern the variety of brain vascularization (1, 2, 10, 16, 17, 19-21). However, there are no studies investigating the technique of corrosion casting combined with 3D modeling. In this study, for the first time, we rendered two different types of 3D reconstruction models of porcine cranial head arteries from two different corrosion casting types. Both techniques revealed clearly, instructive pictures of filled vessels, including also such delicate networks as these of rete mirabile. Also, anastomosing structures that are very difficult to detect or easily damages during dissection can be easily identified at the tip of the tongue. In our opinion, this is seriously advantage of that technique and highlights its suitability for education and other demonstration. Such 3D STL files can be used to produce 3D printed models, as well. In this way, it is thought the problem of replication in corrosion casting will be overcome.

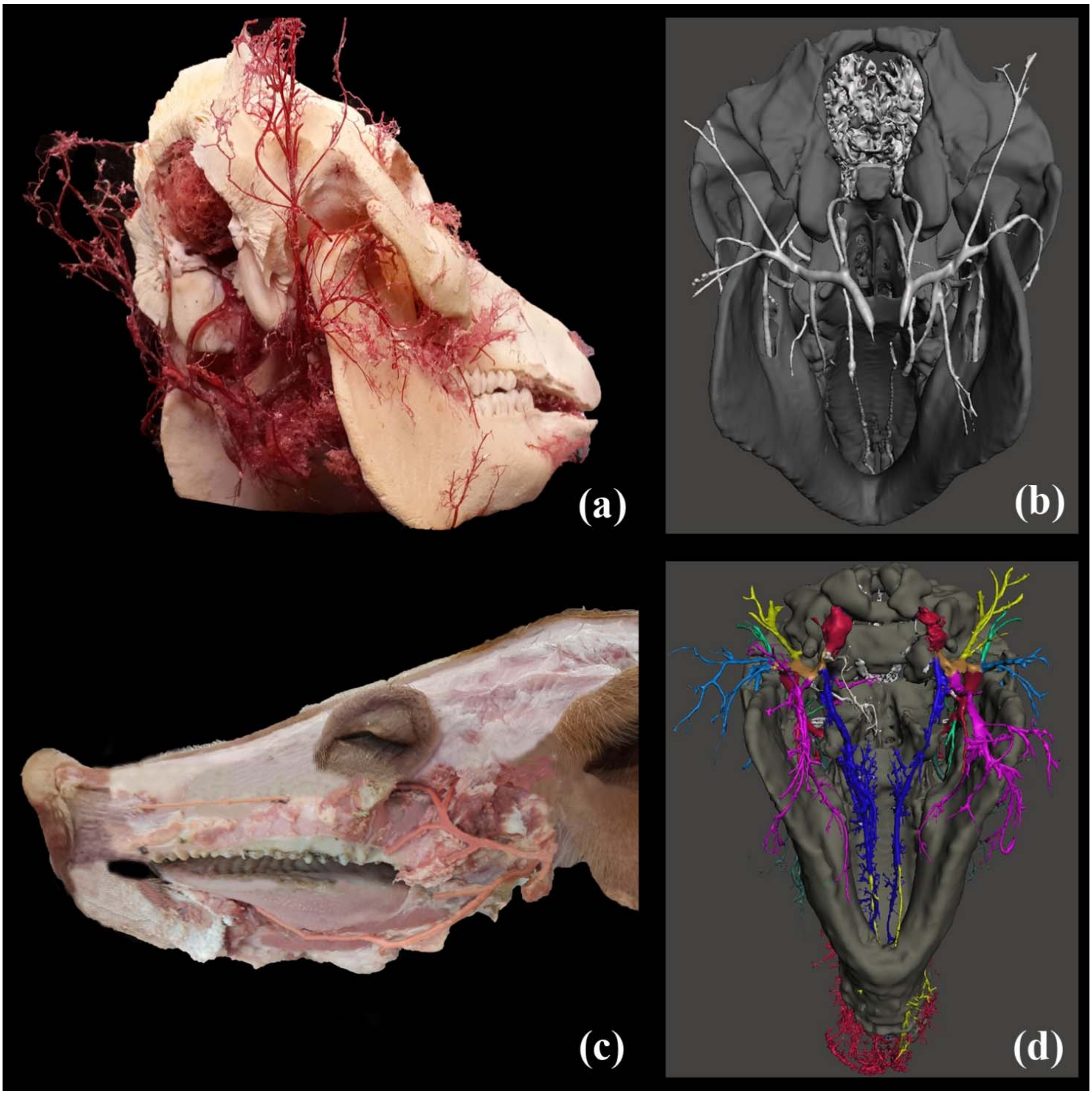

Figure 3. Comparison of the visualization of different corrosion cast and 3D models.
(a) Latero-caudal aspect of the Duracryl Plus corrosion cast specimen, (b) Caudo-ventral aspect of the 3D model of the Duracryl Plus corrosion cast specimen, (c) Lateral aspect of the gelatin corrosion cast specimen after some dissection, and (d) Ventral aspect of the 3D model of the gelatin corrosion cast specimen.

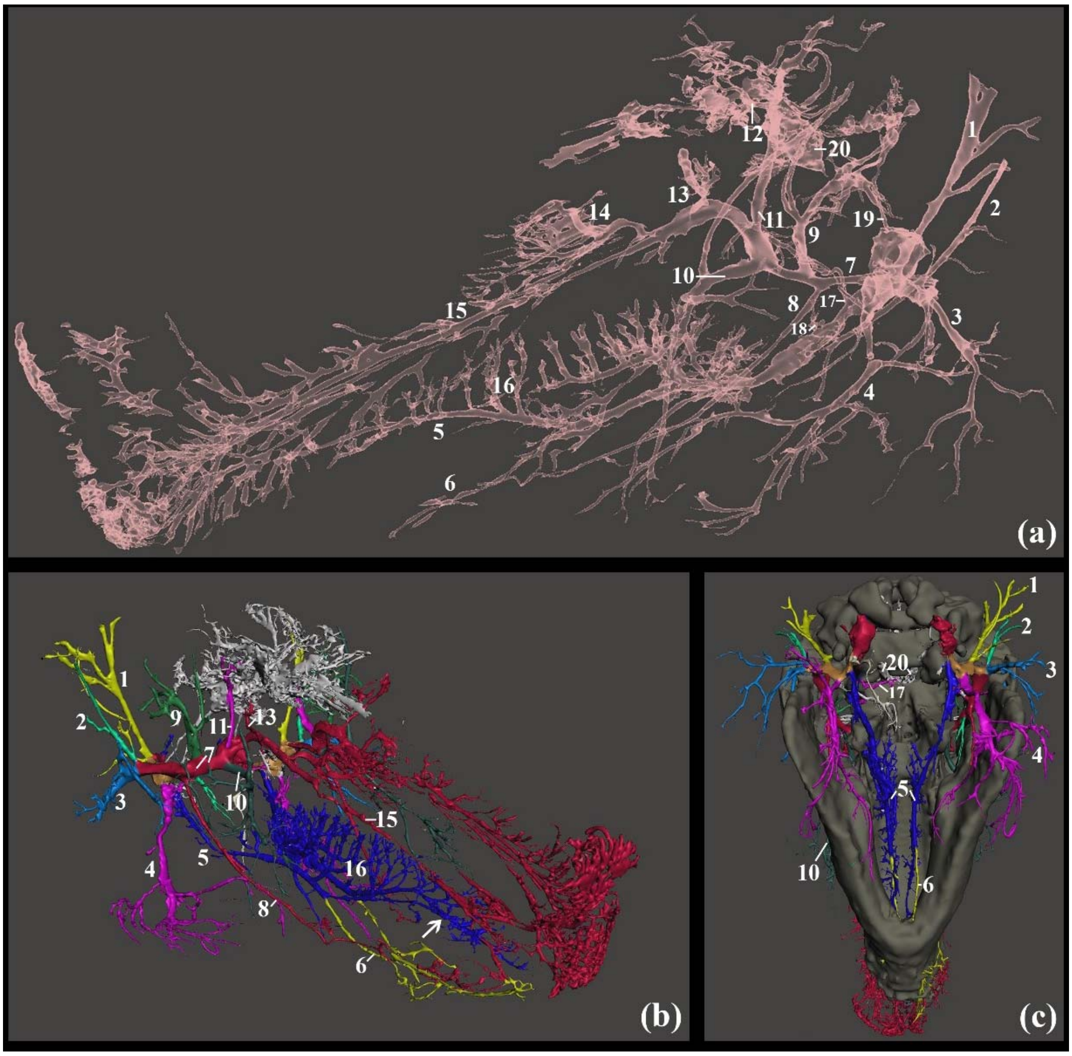

Figure 4. Three-dimensional reconstructed images of the arteries and bones of the pig head.
(a) Latero-cranial aspect of the branches of the left a. carotis communis, (b) Latero-cranial aspect of the colored branches of the arteries and (c) Ventral aspect of the arteries and bones. 1, a. auricularis caudalis; 2, a. auricularis rostralis; 3, a. transversa faciei; 4, a. facialis; 5, a. lingualis; 6, a. sublingualis; 7, a. maxillaris; 8, a. alveolaris mandibularis; 9, a. temporalis profunda caudalis; 10, a. buccalis; 11, a. ophtalmica; 12, a. supraorbitalis; 13, a. malaris; 14, branches of the a. palatina descendens; 15, a. infraorbitalis; 16, a. profunda linguae; 17, a. palatina ascendens; 18, a. pharyngea ascendens; 19, a. carotis interna; 20, rete mirabile epidurale rostrale; anastomose of left and right a. lingualis were indicated by white arrow.

One of the previous studies emphasized that computer-based learning was becoming popular because of decreasing education time, increasing student numbers, and education material costs (7). Parallel to these advantages, it was thought that 3D reconstruction models are useful education material for both theoretical and practical lessons for students in this study. These 3D models can be oriented in any desired position, useful cross-sections can be taken from the desired points and also length and volume measurements can be made. It can be summarized that these are the most important advantages compared to the original casts in this study.

It was also known that the cadaver dissection is the traditional learning material for anatomy and it has some limitations such as financial, ethical, and cultural problems (3, 7). As a matter of fact, the samples obtained by the Duracryl corrosion casting technique are quite fragile. Small vessel structures can be easily broken down when used in education halls. Therefore, these models are usually stored in areas such as museums and exhibition halls (13). On the other hand, the most prominent disadvantage of the gelatin corrosion casting model is that dissection should be performed to make the vessels visible.

As expressed before, this 3D reconstruction CBCT model may contribute to the corrosion cast methodologies and investigations in the pig's head. We concluded that the gelatin corrosion cast technique was much better detail quality on cone-beam computed tomography images than the Duracryl corrosion cast.

Finacial support

This research received no grant from any funding agency/sector.

Ethical Statement

Ethical approval is not applicable for this article.

Conflict of Interest

The authors declared that there is no conflict of interest.

References

1. **Aiyan AA, Menon P, AlDarwich A, et al** (2019): *Descriptive analysis of cerebral arterial vascular architecture in dromedary camel (Camelus dromedarius).* Front Neuroanat, **13**, 67.
2. **Brudnicki W** (2011): *Morphometric analysis of the brain base arteries in fallow deer (Dama dama).* Vet Med, **56**, 462–468.
3. **Chen S, Pan Z, Wu Y, et al** (2017): *The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trail.* Sci Rep, **7**, 575.
4. **Cornillie P, Casteleyn C, von Horst C, et al** (2019): *Corrosion casting in anatomy: Visualizing the architecture of hollow structures and surface details.* Anat Hist Embryol, **48**, 591-604.
5. **De Sordi N, Bombardi C, Chiocchetti R, et al** (2014): *A new method of producing casts for anatomical studies*. Anat Sci Int, **89**, 255-265.
6. **Eberlova L, Liska V, Mirka H, et al** (2017): *The use of porcine corrosion casts for teaching human anatomy*. Ann Anat, **213**, 69-77.
7. **Estai M, Bunt S** (2016): *Best teaching practices in anatomy education: A critical review.* Ann Anat, **208**, 151-157.
8. **Fedorov A, Beichel R, Kalpathy-Cramer J, et al** (2012): *3d slicer as an image computing platform for the quantitative imaging network*. Magn Reson Imagin, **30**, 1323–1341.
9. **Hermiz DJ, O'Sullivan DJ, Lujan HL, et al** (2011): *Constructivist learning of anatomy: gaining knowledge by creating anatomical casts*. Anat Sci Educ, **4**, 98-104.
10. **Jerbi H, Khaldi S, Pérez W** (2016): *Morphometric study of the rostral epidural rete mirabile in the dromedary (Camelus dromedarius, Linnaeus 1758).* Int J Morphol, **34**, 1429-1435.
11. **Kong X, Nie L, Zhang H, et al** (2016): *Do 3d printing models improve anatomical teaching about hepatic segments to medical students? A randomized controlled study*. World J Surg, **40**, 1969-1976.
12. **Li J, Nie L, Li Z, et al** (2012): *Maximizing modern distribution of complex anatomical spatial information: 3D reconstruction and rapid prototype production of anatomical corrosion casts of human specimens.* Anat Sci Educ, **5**, 330-339.
13. **Li K, Kui C, Lee E, et al** (2017): *The role of 3D printing in anatomy education and surgical training: A narrative review*. MedEdPublish, **6**, 31.
14. **Massari CHAL, Pinto ACBCF, De Carvalho YK, et al** (2019): *Volumetric computed tomography reconstruction, rapid prototyping and 3D printing of opossum head (Didelphis albiventris). Int J Morphol*, **37**, 838-844.
15. **Nomina Anatomica Veterinaria** (2017): International Committee on Veterinary Gross Anatomical Nomenclature (ICVGAN), Prepared by the international committee on veterinary gross anatomical nomenclature and authorized by the general assambly of the world association of veterinary anatomists. Sixth Edition, The Editorial Committee Hanover (Germany), Ghent (Belgium), Columbia, MO (U.S.A.), Rio de Janeiro (Brazil).
16. **O'Brien HD** (2017): *Cranial arterial patterns of the alpaca (Camelidae: Vicugna pacos).* R Soc Open Sci, **4**, 160967.
17. **Ocal MK, Erden H, Ogut I, et al** (1999): *A quantitative study of the circulus arteriosus cerebri of the camel (Camelus dromedarius).* Anat Hist Embryol, **28**, 271-272.
18. **Selle D, Preim B, Schenk A, et al** (2002): *Analysis of vasculature for liver surgical planning*. IEEE Trans Med Imaging, **21**, 1344-1357.
19. **Shatri J, Cerkezi S, Ademi V, et al** (2019): *Anatomical variations and dimensions of arteries in the anterior part of the circle of Willis*. Folia Morphol, **78**, 259–266.
20. **Simoens P, Lauwers H, De Geest, et al** (1987): *Functional morphology of the cranial retia mirabilia in the domestic mammals.* Schweiz Arch Tierheilkd, **129**, 295-307.
21. **Wang XR, Liu Y, Zhang LP, et al** (2012): *Comparative anatomical study of the epidural retia mirabile in the yak and cattle*. Asian J Anim Vet, **7**, 884-890.