Original Article

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Three-Dimensional Modeling of Sheep Humerus by Photogrammetry

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Abstract

The increasing use of three-dimensional models, one of the developing technologies in education, directs researchers to new studies in this field. The aim of this study is to create a low-cost model for the first time in long bones using the photogrammetry method and to contribute to the easy production of bones that are difficult to obtain in the future. In this study, images of sheep humerus were arranged and three-dimensional modeling was done in Cinema 4D software. The model, whose design was completed, was printed with a three-dimensional printer using Polylactic Acid (PLA) filament. In this study, for the first time, a three-dimensional model of the sheep humerus, which is a long bone, was created using the photogrammetry method, printed and compared with the real bone. It has been seen that anatomical structures can be designed and printed in the most realistic way, using only photographs, without the use of three-dimensional reconstruction devices. However, it has been observed that small artifacts occur on the contact surface between the PLA filament used for printing and support during the printing process. It was considered that this issue could be resolved in subsequent studies by using different support filaments during the printing of models.

Keywords: 3D, anatomical materials, anatomy, modeling, sheep

Introduction

In anatomy education, the subject of osteology is covered by using traditional teaching methods such as books, atlas, drawings, and real bone materials. Since books, atlas, and drawings are two-dimensional, they are limited to the student's imagination (Collins, 2008; Türk Kaya & Arıcan, 2014). On the other hand, three-dimensional (3D) real bone materials have disadvantages such as cost, intensive labor, lousy odor, ethical concerns, and length of preparation times due to the methods used in the preparation stage (Couse & Connor, 2015; Rowley, 2015; Tompsett, 1970). With the developing technology, the use of 3D materials in anatomy education is becoming widespread (AbouHashem et al., 2015; McLachlan et al., 2004; Wainman et al., 2021). Three-dimensional models can be made using magnetic resonance (MR), computed tomography (CT) data, 3D scanners, and various computer programs (Azer & Azer, 2016; Chae et al., 2020; Lim et al., 2016; Özkadif, 2015; Wilhite & Wölfel, 2019). Many researchers have performed 3D reconstruction studies on the skeleton, circulation, respiratory, digestive, urinary systems, and sensory organs using MR or CT in the field of anatomy (Bakıcı et al., 2019; Endo et al., 2009; Harrysson et al., 2003; Martinelli et al., 1997; McMenamin et al., 2014; Özkadif, 2015). In addition to the high cost of using these devices, their use in large-sized animals is also limited. For this reason, the reconstruction of anatomical structures has been achieved by using the photogrammetry method in large animals and anatomical structures that are difficult to measure (Labens et al., 2013; Karabork, 2009; Kurt et al., 2022). The photogrammetry method, which includes low cost, is considered a reliable method in the examination and evaluation of bones in the field of anatomy (Mikhail et al., 2001; Schenk, 2005; Şeker et al., 2002). Three-dimensional models were created with the photogrammetry method in different animal species (Koçak et al., 2017; Kurt et al., 2022; Labens et al., 2013; Wesencraft & Clancy, 2019).

Measurements were taken on the 3D model of the glenohumeral joint in sheep, cats, and rabbits, and differences were determined between species (Karabork, 2009), the reconstructions of horse hoof were made and their volumes were calculated (Labens et al., 2013), the scapula was modeled in 3D and the morphometric values of the scapula were revealed (Kurt et al., 2022), and the general body

A part of this study was presented as an oral presentation in the congress named "International 19 May Innovative Scientific Approaches Congress" on December 21, 2020.

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dimensions of sea lions were also determined by this method (Meise et al., 2014).

In this study, it was aimed to design and print the anatomical structures in a long bone in the most realistic way by using the photogrammetry method in sheep humerus. This method, which can be used on different types of bones in the future, will contribute to the reproduction of bones used in practical and theoretical training.

Methods

For the design, a sheep's humerus was photographed from various angles with the Olympus C-5060 digital camera. In order to model the humerus in three dimension, measurements were taken from four different points on the bone: the length between the caput humeri and the extremitas distalis, the length from the tuberculum majus to the condylus lateralis, the width at the midpoint of the corpus humeri, and the width of the trochlea humeri (Figure 1). Mitutoyo (CD-30Dc/Japan) digital caliper was used for the measurement. After the photos were transferred to the computer environment, they were edited with Adobe Photoshop CS6 program and the humerus model design was created. Then, based on the measurements of the real bone, the outline of the outer diameter of the bone was obtained with the ring-shaped tools in the Cinema 4D software (Figure 2A). By combining these rings with the loft feature in Cinema 4D software, the diameter of the bone model and the structure of the model were created by arranging the polygons in the same program. After the created model was saved in ".obj" format, it was transferred to Zbrush software to reveal the anatomical structures on the bone more clearly (Figure 2B). Anatomical structures in the extremitas proximalis and extremitas distalis of the humerus were clarified. The model was transferred to the substance painter program to reveal the articular surfaces in these regions (Figure 2C). The model was coated to make the design look like reality. It took approximately 12 hours to model the 3D model from photos. After all these stages were completed, the model, which was transferred

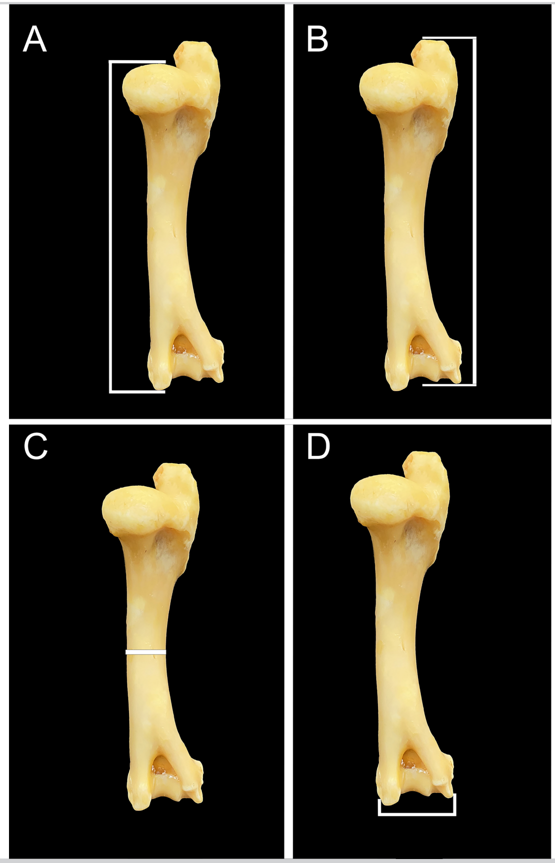

Figure 2.
Measurements Are Taken From the Humerus Bone. Length Between Caput Humeri and Extremitas Distalis (A), Length From Tuberculum Majus to Condylus Lateralis (B), Width at Midpoint of Corpus Humeri (C), With the Measurement of Trochlea Humeri (D).

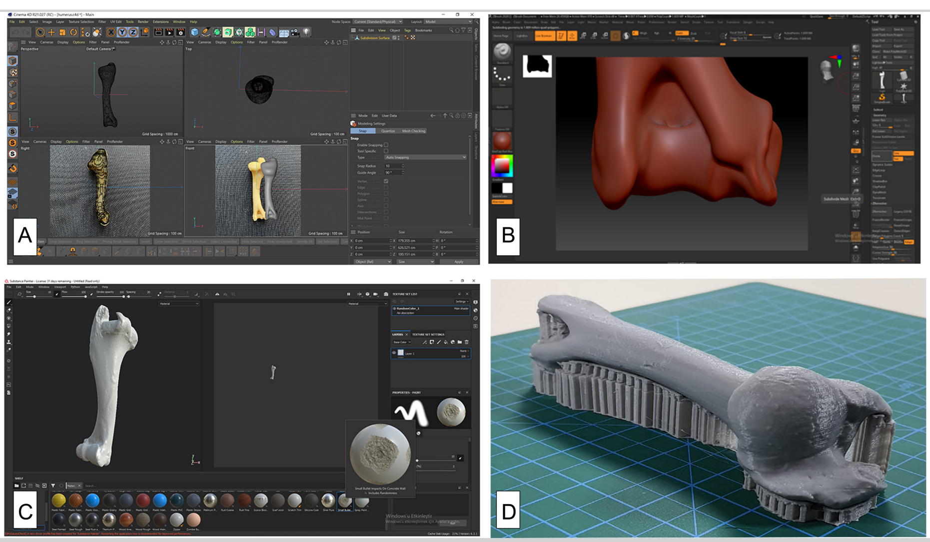

Figure 1.
Obtaining the Outline of the Outer Diameter of the Bone With the Ring-Shaped Tools in Cinema 4D Software Based on the Dimensions of the Real Bone (A), Using the Zbrush Software to Reveal the Anatomical Structures on the Created Model More Clearly (B), Coating the Model in the Substance Painter Program to Reveal the Joint Faces (C), Printing the Completed Model From a 3D Printer Using PLA Filament (D).

Table 1.
Printing Settings of PLA Filament

Print Settings	PLA
Nozzle size	0.4 mm
Printing temperature	220ºC
Build plate temperature	70ºC
Support	Enable
Fan speed	100%
Infıll	30%
Print speed	35 mm/s
Retraction	Enable
Print time	16 hours
Layer height	0.12 mm

Note: *Printing speed, nozzle, and table temperature values may vary according to the filament and 3D printer brands. PLA, Polylactic Acid

to Cinema 4D software, was rendered and saved in "stl." format for future use. The model, whose design was completed, was printed from a Fused Deposition Modeling 3D printer (Creality Ender 3 V2, Chinese) using PLA filament (Figure 2D). The printing properties of PLA filament are given in Table 1.

Results, Discussion, and Conclusion

In recent years, models made with 3D printing technology in the field of anatomy have increased, and the advantages and disadvantages of the models obtained by this method are discussed (Bakıcı et al., 2021).

To obtain 3D sheep humerus, measurements with a digital caliper were taken from real sheep humerus. The measurement points and measurements that were taken from the sheep humerus are presented in Figure 2 and Table 2.

Based on these measurements and the photographs, a 3D design was made with the computer-aided Cinema 4D program. A bone model was obtained by printing this design with a 3D printer with

Table 2.
Measurements Taken for 3D Modeling

Measurements	Length
A*	158.22 mm
B**	166.15 mm
C***	23.22 mm
D****	37.11 mm

Note: *The length between the caput humeri in the extremitas proximalis of the humerus and the condylus medialis in the extremitas distalis (Figure 2A).
**The length from the tuberculum majus of the humerus to the condylus lateralis was measured as 166.15 mm (Figure 2B).
***The width at the midpoint of the corpus of the bone was measured as 23.22 mm (Figure 2C).
****The width of the trochlea humeri located distal to the bone was measured as 37.11 mm (Figure 2D).

Table 3.
An Observational Comparison of the Model Obtained With Real Bone and PLA Filament in Terms of Anatomical Structures

Anatomical Structure	Real Bone	PLA
Tuberculum majus	+++	+++
Tuberculum minus	+++	+++
Facies m. infraspinati	+++	++
Tuberositas teres minor	+++	+++
Tuberositas teres major	+++	+++
Crista humeri	+++	+++
Fossa olecrani	+++	+++
Fossa radialis	+++	+++

PLA, Polylactic Acid

PLA filament. The similarities and differences between this model and the real bone are shown in Table 3. In a study on sheep scapula, it is mentioned that there may be losses in anatomical structures in the removal of support filaments during the 3D modeling phase (Kurt et al., 2022). Similarly, although many anatomical structures on the bone model created in our study were fully revealed, the "fascies m. infraspinati" was damaged during the compression angle and the removal of the model from the support materials. This situation made us think that it might be due to using the same PLA filament as a support material in the models produced with PLA filament. In future studies, it is planned to change the support filament and investigate its effect on the results. In the literature, the weights of the 3D models created in the digital horse skeleton (Bakıcı et al., 2021) and thoracic limb bones (de Alcântara Leite dos Reis et al., 2019) in horses and the scapula in sheep (Kurt et al., 2020) have been compared with the real bone weights. These studies have reported that the appearance and dimensions of the anatomical structures are exactly similar to the real bone, and the 3D-printed model is lighter than the real bone. In our study, it was determined that the weight of the bone model printed with PLA was 40 g, and the weight of the real bone was 121 g. This supports the finding that the 3D-printed model is lighter than the real bone.

The photogrammetric method was used in studies (Kurt et al., 2022; Labens et al., 2013; Wesencraft & Clancy, 2019). As a result of these studies, it has been reported that photogrammetry is a method with advantages such as its low cost and easy accessibility and its ability to create a model in a computer environment with exact dimensions similar to the real bone. With this study, it has been demonstrated again that this method has the advantages mentioned in the literature. In this respect, we think its use in veterinary anatomy will be widespread.

In conclusion, with this study, a 3D model of the long bone (the sheep humerus) was created for the first time using the photogrammetry method, printed, and compared with the real bone. While creating this model, PLA filament was used for both support and model creation in the 3D printer. The resulting model was mainly similar to the real bone, but minor artifacts occurred in an anatomical structure on the surface where the support material was in contact. For this reason, it is thought that artifacts can be prevented using different support filaments while printing bone models in 3D printers. In addition, it is predicted that in creating skeletal material belonging to extinct or endemic animals, 3D modeling can be made in a computer environment using only photographs, and anatomical models identical to the real bone can be obtained with 3D printing technology.

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