Research Article

BIOMEDICAL
Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2023.52.008256

3D-Printed Anatomical Models Allowing for Customization

Arya Afzali[1]*, Collin Clarke[1], Anand Dhaliwal[1], Kevin Yu[1] and Jose Puglisi[2]

[1]*California Northstate University College of Medicine Class of 2024, USA*

[2]*California Northstate University College of Medicine Faculty, USA*

***Corresponding author:** Arya Afzali, California Northstate University College of Medicine Class of 2024, USA

ARTICLE INFO

Received: July 11, 2023

Published: August 25, 2023

Citation: Arya Afzali, Collin Clarke, Anand Dhaliwal, Kevin Yu and Jose Puglisi. 3D-Printed Anatomical Models Allowing for Customization. Biomed J Sci & Tech Res 52(3)-2023. BJSTR. MS.ID.008256.

ABSTRACT

The use of cadavers in medical education is common, but the costs and limited availability associated with this practice have caused educators to look for alternatives such as 3D printed models (3DPM). A limited amount of studies have shown 3DPM to be a valuable educational tool that offers an improved experience compared to 2D images. Most of these studies have used 3DPM designed using the results of CT/MRI scans, offering extremely accurate representation of the human body. However, the use of CT/MRI scans to create 3DPM does not allow for customization of which structures are represented or clear delineation of individual anatomical structures.

Study Objectives: We hypothesized that creating multiple 3DPM of the human knee based on anatomically correct artistically renderings with individually designed components as opposed to CT/MRI DICOM data would offer medical students a more manageable avenue for creating 3DPM that would be suitable for introductory medical education.

Methods: In this study we created multiple 3DPM of the human knee using artistic renderings that were manipulated in Blender and printed via a stereolithography (SLA) 3D printer. We created three different knee models for this study (one with the femur removed, one with the tibia removed, and one with no structures removed) to expose areas of the knee joint that are often difficult to find in a cadaver.

Results: The study found that 3DPM based on artistic renderings can provide a viable alternative for educators seeking to create models that will be able to isolate anatomical structures of interest, as well as the ability to print models with selective levels of tissue included.

Conclusion: Exploration of this new approach to creating 3DPM with such advantages improves accessibility for anatomy education programs who do not have access to CT/MRI DICOM data or the usage of cadavers to teach students.

Keywords: Teaching of Anatomy; Medical Student; 3D-Printing; Blender; Computer-Aided Instruction; Computers in Anatomical Education; Medical Education

Aberrations: CNUCOM: California North state University College of Medicine; CT: Computed Tomography; SLA: Stereolithography; 3DPM: 3D Printed Models; 3DI: 3D Reconstructed Images; 2DI: 2D Images

Introduction

The usage of cadavers for medical anatomy education can be dated back centuries. With advances in technology and the high costs of purchasing yearly cadavers, medical educators have looked for other methods of education to supplement the usage of cadavers [1]. These supplemental methods are often PowerPoint presentations, and two-dimensional images from atlases, radiographs, and dissection photos. However, multiple studies have shown that 3D visualization methods are significantly more effective than 2D visualization methods in medical anatomy education [2]. Additionally, distance learning due to the Covid-19 pandemic has limited the usage of cadavers in many parts of the world [3]. Three-dimensional printing is a novelty that has shown promising results in replicating human anatomy in a cost-effective manner. Many studies have been conducted in the past few years testing the efficacy of 3D printing in medical anatomy classes [4-14]. Few studies have truly compared different anatomical teaching methods amongst first-year medical school students with minimal formal exposure to anatomy. Most studies have compared the usage of lecturing supplemented with 3D printed models compared with control groups. Su, et al. compared didactic seminars with and without the usage of 3D printed models. This study showed a significant improvement in learning using 3D models but failed to compare the 3D models with other supplemental material [6].

Another study by Lane et al investigated the efficacy of 3D printing models, but also had a control group consisting solely of a PowerPoint presentation. This study also used second-year medical students with a baseline knowledge of anatomy, making it difficult to analyze 3D printed models as a learning tool for first novice medical anatomy learners [9]. Karsenty et al did a similar study with 5th-year French medical students with similar results. These studies have confirmed that 3D printed models improve knowledge and learner satisfaction in comparison with didactics that do not utilize models. However, this does not provide sufficient data for the impact of 3D printed models in the initial introduction of anatomy in medical education, as most anatomy programs do not rely solely on lectures but use a variety of supplemental materials. One study that has made a direct comparison of 2D images versus 3D printed models was conducted by Hojo et al. They compared the use of 3D printed models versus studying with a textbook. Students in the experimental and control groups were given 5 minutes each to study using their assigned resource. The researchers found significant differences in short- and long-term test scores between the two groups. This study showed that 3D printed models could serve as a viable, arguably superior, replacement for traditional educational tools such as textbooks [11]. Yi et al compared the usage of 3D printed models (3DPM) with 3D reconstructed images (3DI) and 2D images (2DI) of the ventricular system. This study found a significant difference in the change in test scores between the 3DPM and 3DI compared with the 2DI group's change in test scores.

However, no significant difference was found between the 3D printed models and the 3D reconstructed images. Chen et al. were the first to conduct a RCT using third-year medical students who had not been exposed to anatomy prior to the study. A comparison was made between cadaveric skulls, 3D printed skulls, and 2D atlases. This study showed a significant difference in improvement in pre and post-test scores in the 3D printed test group compared with the other two groups [13]. We hope to build off of Chen et al's study with the creation of 3D printed knee models that are capable of customization prior to printing to display the anatomic structures of interest. Models traditionally based on CT scans are typically accompanied by a large number of artifacts and noise, as well as an oftentimes lack of clear delineation between individual anatomical structures. Elimination of such noise requires the use of post-processing with high segmentation thresholds and smoothing algorithms, which inevitably result in loss of key anatomical details. Otton et al found that arterial motion during a CT scan caused vessels to appear bigger than they actually were. The challenges posed by using a CT scan to create a 3D model may make creating as well as learning from such models difficult for medical students who are becoming familiar with the anatomy for the first time. Using an anatomically correct 3D model created via an artistic rendering of individual anatomic components rather than computed tomography (CT) scans of real humans, we aim to create custom printed models that offer a practical way of isolating structures of interest within the human anatomy.

Traditionally, hard and soft tissue structures are not able to be printed simultaneously using elastical and hard 3D printed resins in conjunction with standard desktop printers. Thus, in order to create models with a high degree of realism, our goal will also be to explore adhesive options for assembling multi-component models whose individual anatomical components such as bone, vessels, and connective tissues are represented by materials of realistic density.

Methods and Results

An anatomically correct 3D file of a human leg complete with artistic representations of four bones, twenty muscles (later omitted for clarity), thirtyone connective tissue structures, major arterial/venous systems, nerves, and lymphatics (later omitted) was acquired from the online model marketplace Turbosquid. It was then truncated via Blender to only include the knee joint and its main structures (see Index), as well as separated by material to isolate each individual anatomical structure. Structures came pre-rendered, and anatomical accuracy was confirmed via cross-referencing between the model and Essential Anatomy [4]. (Figure 1). Polygon counts were increased exponentially via the subdivide function in order to maximize the level of printed model detail. Initially, every component surrounding the knee joint was rendered and exported individually as a .obj file and printed via the Formlabs 3B+ 3D printer through the PreForm 3D printing software using Elastic 50A/Flexible 80A for soft tissue structures and Form labs Model Resin for bone to allow for maximal realism (Figures 2,3 & 4). Numerous attempts were made at using adhesives to assemble the model using the structures printed with both hard and soft resin. Loctite super glue, standard craft hot glue, rubber cement, Gorilla glue, wood glue, and multi-purpose construction grade epoxy were all tested in creating a stable bond between the model components of differing density.

DOI: 10.26717/BJSTR.2023.52.008256

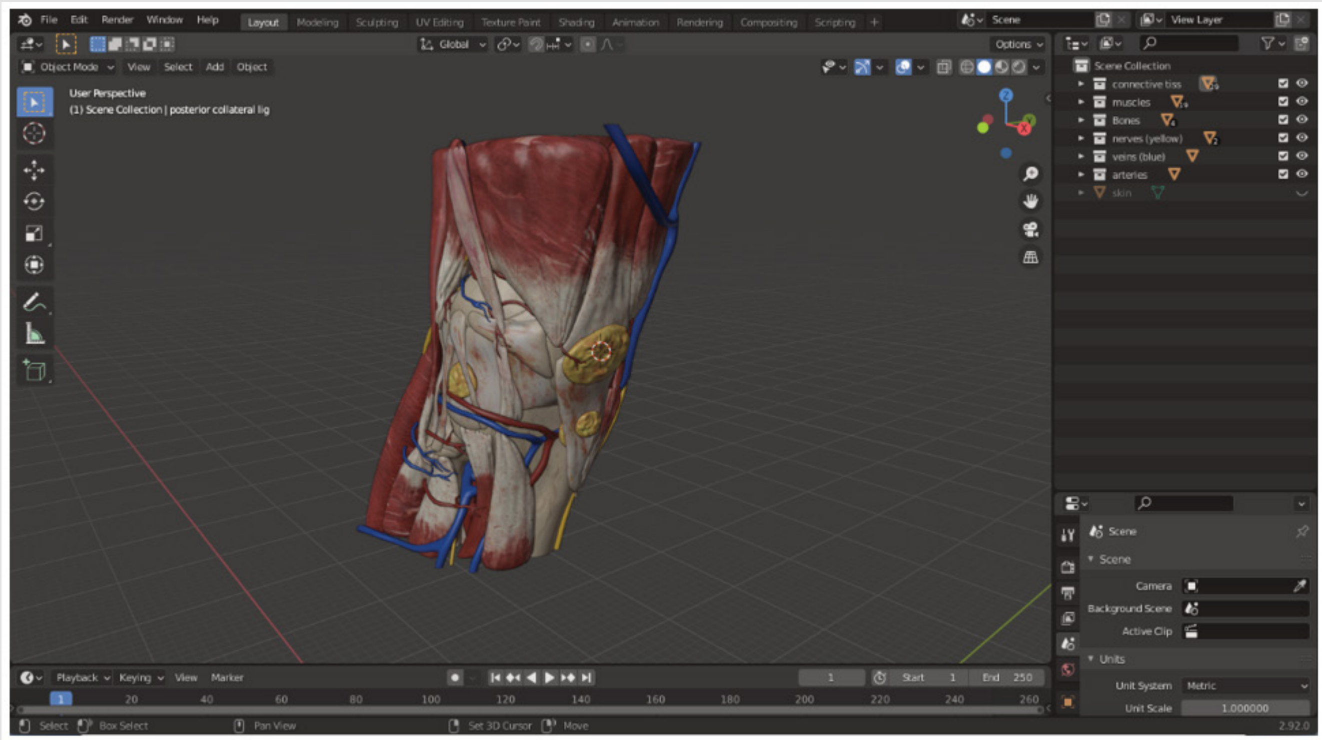


Figure 1: Truncated knee model in Blender with 56 individually rendered anatomical structures.

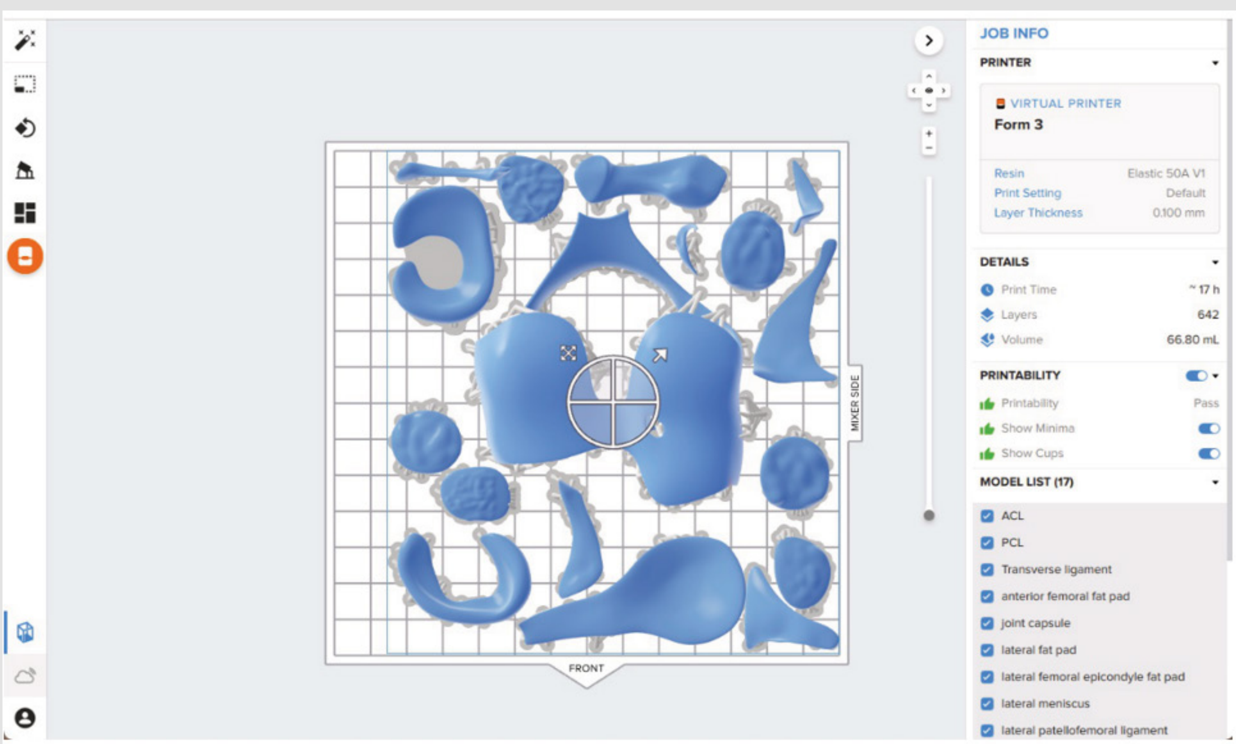


Figure 2: Example of individually rendered connective tissue structures prepared for 3D printing in the 3D printing software PreForm.

 DOI: 10.26717/BJSTR.2023.52.008256

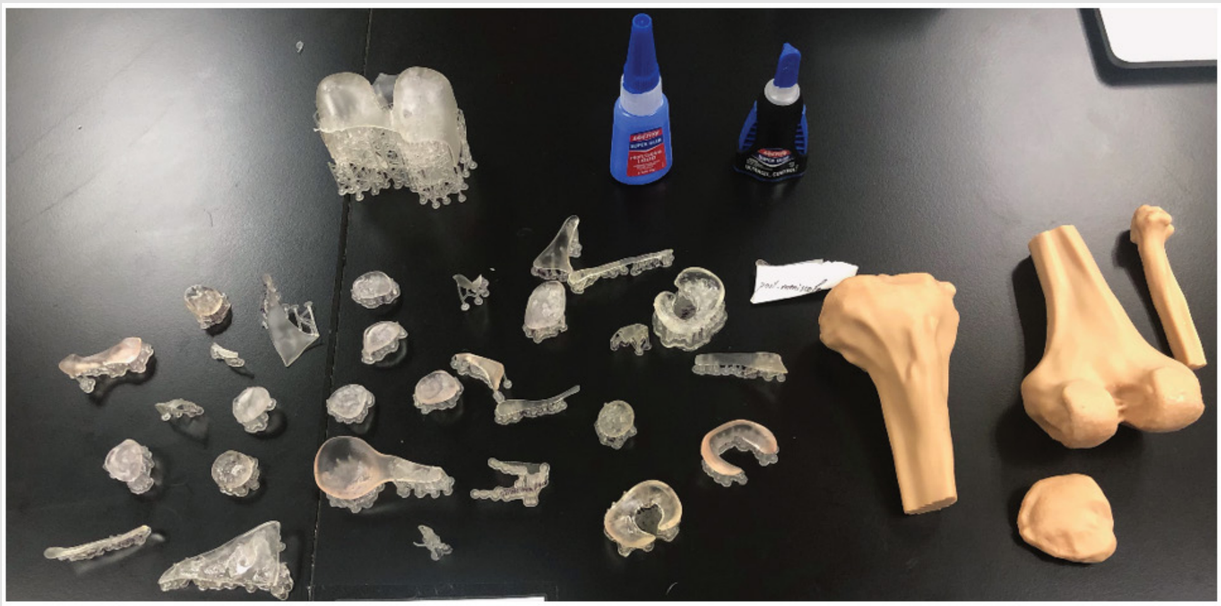


Figure 3: Connective tissue structures printed in Elastic 50A Resin; Bones printed in Model Resin.

Figure 4: Arterial system surrounding the knee joint printed in Elastic 50A Resin.

These attempts were ultimately unsuccessful, as no one adhesive or combination thereof provided adequate purchase between components so as to have a durable model. Attempts were also made to contact the manufacturer of the proprietary resins, Formlabs, in efforts to better guide our adhesive choices. Ultimately, this did not yield an alternative method of assembling the soft and hard resin-based structures as one multi-component model. Attempts were then directed towards printing the entirety of the digital 3D knee and all of its significant structures as a solid one-piece print with Formlabs White V4 Resin, thereby enhancing the structural stability of the model and its durability (Figures 5 & 6). After successfully printing a knee model containing bones, arteries, veins, nerves, and connective tissue com-

DOI: 10.26717/BJSTR.2023.52.008256

ponents as a single unit (Figures 7a & 7b), additional models were easily customized via Blender by checking off the 'exclude from view layer' box in the scene collection tab of Blender. Using this method, we were successful in isolating the connective tissue structures of the proximal and distal aspects of the knee with emphasis on the junction between the femur and tibia (Figures 8-10). Rendering the models in this way allowed for the internal structures of the joint to be clearly visualized, with no need in using segmentation software to remove artifact/noise, and no loss of the intended structures.

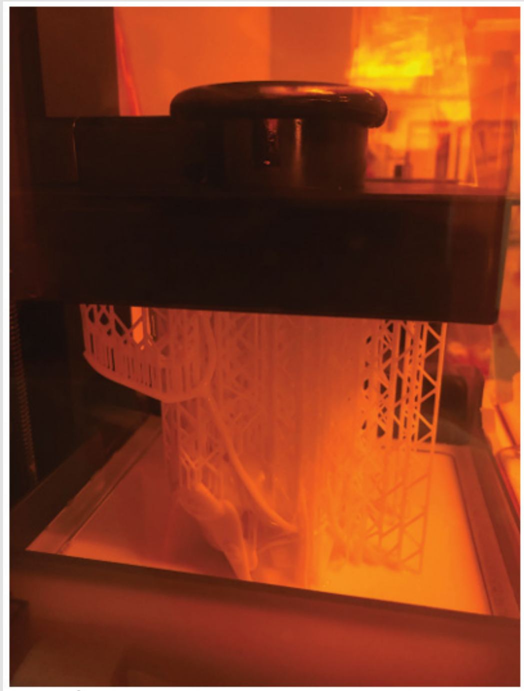


Figure 5: 3D printing the knee joint (bones, connective tissue, arterial and venous systems, nerves) in Formlabs White V4 Resin.

Figure 6: 3D print of knee joint with scaffolding (bones, connective tissue, arterial and venous systems, nerves) in Formlabs White V4 Resin.

DOI: 10.26717/BJSTR.2023.52.008256

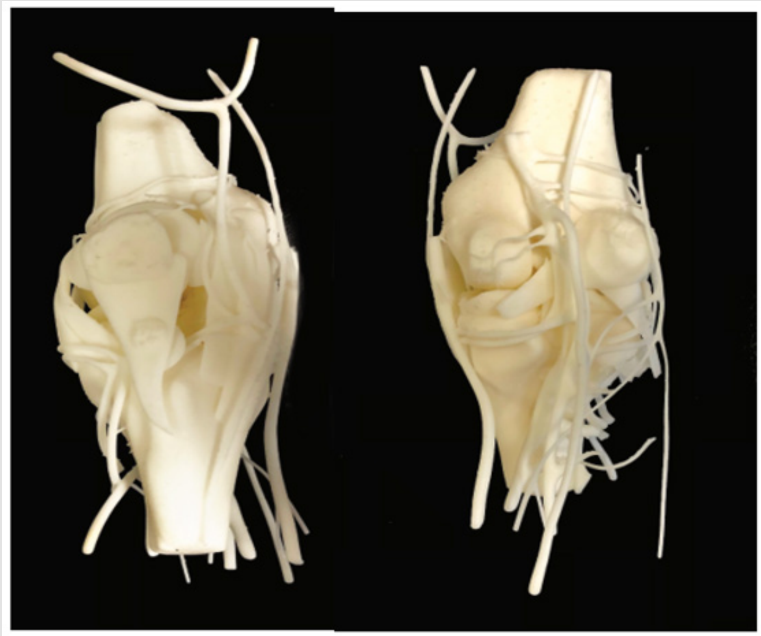


Figure 7a & 7b: Anterior/posterior views of 3D printed knee joint (bones, connective tissue, arterial and venous systems, nerves) in Formlabs White V4 Resin.

Figure 8: Superior view of tibial segment of knee joint (bones and connective tissue) in Formlabs White V4 Resin.

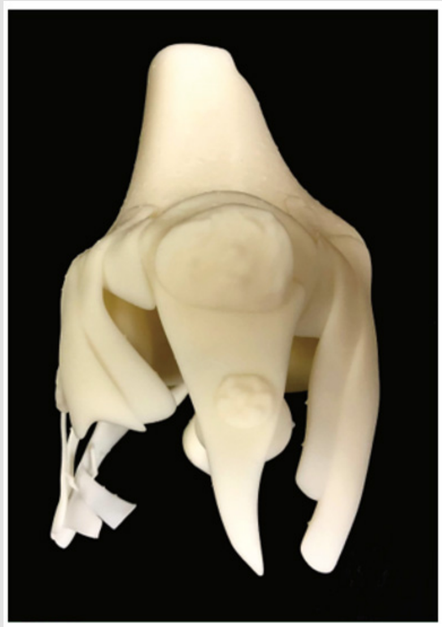


Figure 9: Anterior view of femoral segment of knee joint (bones and connective tissue) in Formlabs White V4 Resin.

Figure 10: Inferior view of femoral segment of knee joint (bones and connective tissue) in Formlabs White V4 Resin.

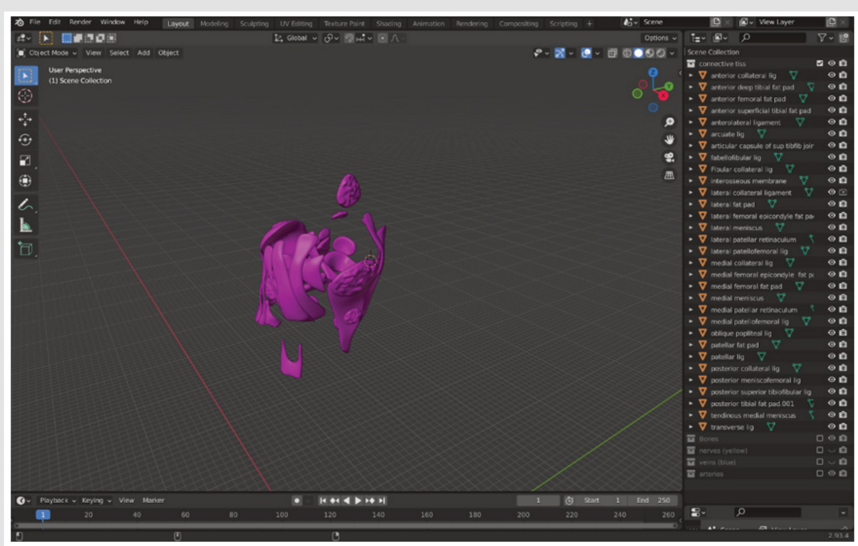
 DOI: 10.26717/BJSTR.2023.52.008256

Discussion and Conclusions

3D printed models have been proven to be a valuable tool in anatomical education. Numerous studies have used CT scans to create such models providing extremely accurate spatial resolution of anatomical structures, especially rare anatomic pathologies that may not be present in most cadavers [10]. Creating 3D printed models based on CT scans allows for the most accurate representation of human body parts. However, the use of CT scans to create 3D models does not allow for simple customization of which structures are represented in a given model or clear delineation of individual anatomical structures. For students learning anatomy for the first time it can be challenging to understand the relationship between anatomical structures without a clear separation of structures, especially in an area like the knee that has multiple layers of muscle, cartilage, arterio-venous system, and bursas [15]. In this study we used an artistic rendering of a human knee to create a 3D model, thus illuminating a pragmatic alternative to traditional models based upon CT scans. This allowed for simple customization of the model by checking off boxes to include only the exact anatomical structures that were deemed pertinent by the educators at California Northstate University College of Medicine (CNUCOM). The use of an artistic rendering also allowed us to create models with selected structures removed to improve visualization of deep internal structures that are often difficult to make apparent on a cadaver. The creation of two separate models of the human knee, one with the femur removed (Figures 8) and the other with the tibia removed (Figures 9 & 10) allowed for improved visualization of the internal structures of the knee joint compared to a third model in which no bones and tissues were removed (Figures 7a & 7b). This third model serves as a comparison similar to a CT scan-based model, in which clear delineation of deep anatomical structures on visual examination proves challenging for a first-time learner, thus further reinforcing the potential value of our method.

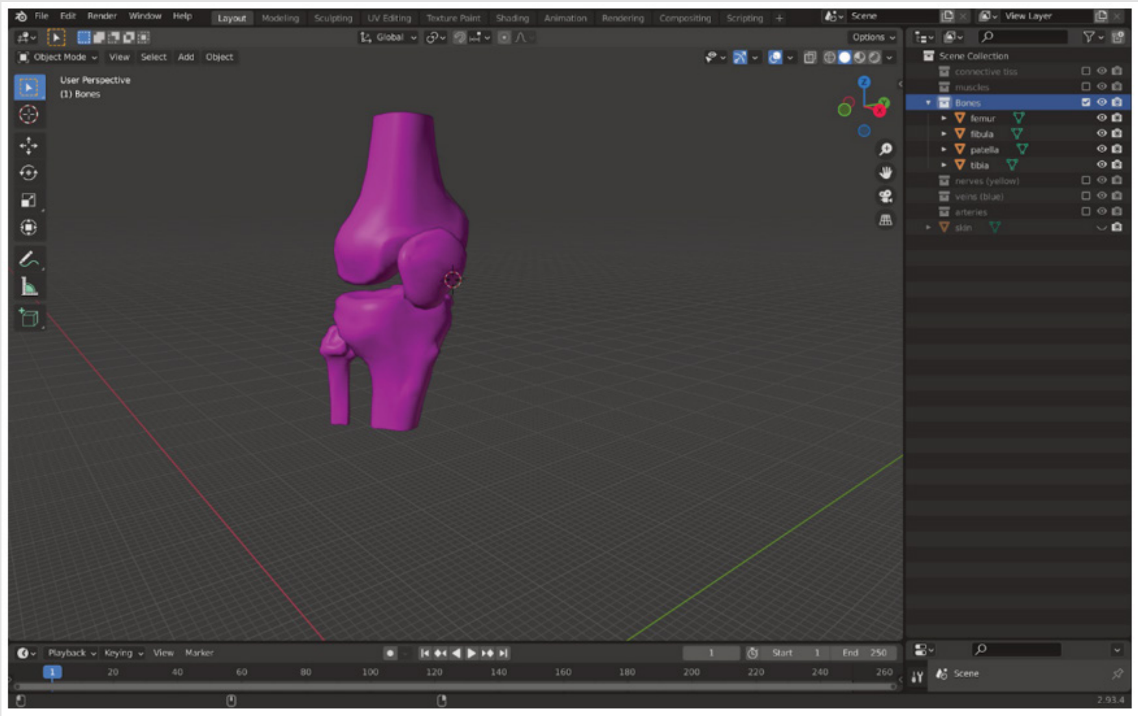
Future Directions

At the time of the creation of these models, the first-year medical students at CNUCOM had already completed their musculoskeletal course that included the use of cadavers to teach anatomy. We hypothesize that this model will be a useful tool in the initial component of anatomical education when most students have little to no background knowledge in anatomy. To test this hypothesis, we plan on conducting a randomized control trial with the next cohort of first year medical students at CNUCOM before they begin any courses involving anatomy. We plan to separate participants into a control group (didactics with 2D images and the use of a cadaver), and two test groups (one group that utilizes didacts and a model generated from CT images, and one group that utilizes didactics with models generated from the 3D anatomically correct artistic renderings with only the structures deemed pertinent). These groups will be tested on their knowledge of the anatomy of the human knee before and after a learning session. We will be testing whether presenting 3D anatomically correct artistic renderings customized to showcase only pertinent structures will allow for better learning compared to the anatomically correct CT models (that are more realistic as they are from an actual patient but will have limited customizability and visibility due to inability to omit certain structures irrelevant to the topics being learned). With this study, we are hoping to see if 3D anatomically correct artistic renderings could be an alternative, possibly better, learning aid when compared to cadavers and 3D CT models utilized by most medical schools. Additionally, our subsequent cohort of medical students have begun a similar project using our method to create customizable 3D-printed models of the upper extremity, thus highlighting its practicality and ability to inspire future generations of students through anatomical education (Index 1-3).

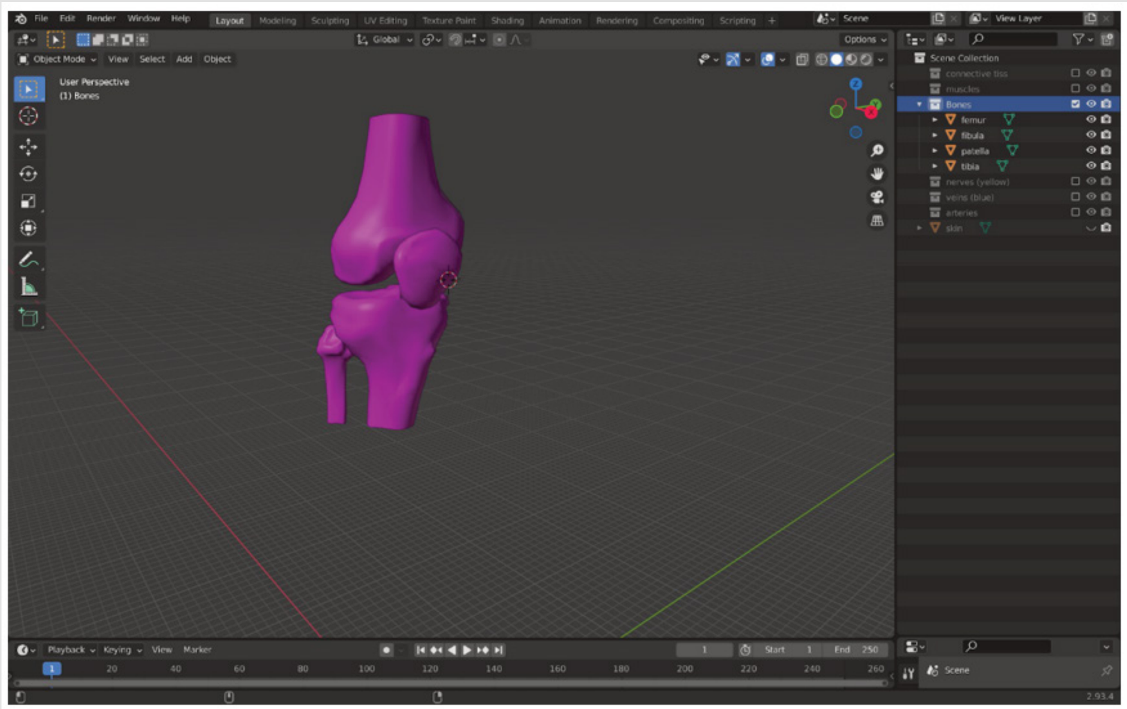


Index 1

DOI: 10.26717/BJSTR.2023.52.008256



Index 2



Index 3

References

1. Ghazanfar H, Rashid S, Hussain A, Ghazanfar M, Ghazanfar A, et al. (2018) Cadaveric Dissection a Thing of the Past? The Insight of Consultants, Fellows, and Residents. Cureus 10(4): e2418.
2. Triepels CPR, Smeets CFA, Notten KJB, Kruitwagen RFPM, Futterer JJ, et al. (2020) Does three-dimensional anatomy improve student understanding? Clin Anat 33: 25-33.
3. Franchi T (2020) The Impact of the Covid-19 Pandemic on Current Anatomy Education and Future Careers: A Student's Perspective. Anat Sci Educ 13(3): 312-315.
4. Xuehan Yi, Chenyu Ding, Hao Xu, Tingfeng Huang, Dezhi Kang, et al. (2019) Three-Dimensional Printed Models in Anatomy Education of the Ventricular System: A Randomized Controlled Study, World Neurosurgery 125: e891-e901.
5. Israel Valverde, Gorka Gomez, Nick Byrne, Shafkat Anwar, Miguel Angel Silva Cerpa, et al. (2021) Criss-cross heart three-dimensional printed models in medical education: A multicenter study on their value as a supporting tool to conventional imaging Anatomical Sciences Education (IF5.958) 15(4): 719-730.
6. Su W, Xiao Y, He S, Huang P, Deng X, et al. (2018) Three-dimensional printing models in congenital heart disease education for medical students: A controlled comparative study. BMC Med Educ 18(1): 178.
7. Mogali SR, Yeong WY, Tan HKJ, Tan GJS, Abrahams PH, et al. (2018) Evaluation by medical students of the educational value of multi-material and multi-colored three-dimensional printed models of the upper limb for anatomical education. Anat Sci Educ 11(1): 54-64.
8. Lim KHA, Loo ZY, Goldie SJ, Adams JW, McMenamin PG, et al. (2016) Use of 3D printed models in medical education: A randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. American Association of Anatomists 9: 213-221.
9. Lane JC, Black JS (2020) Modeling Medical Education: The Impact of Three-Dimensional Printed Models on Medical Student Education in Plastic Surgery. J Craniofac Surg 31(4): 1018-1021.
10. Karsenty C, Guitarte A, Dulac Y (2021) The usefulness of 3D printed heart models for medical student education in congenital heart disease. BMC Med Educ 21: 480.
11. Daisuke Hojo, Koji Murono, Hiroaki Nozawa, Kazushige Kawai, Keisuke Hata, et al. (2019) Utility of a Three-Dimensional Printed Pelvic Model for Lateral Pelvic Lymph Node Dissection Education: A Randomized Controlled Trial. Journal of the American College of Surgeons 229(6): 552-559.
12. Chen S, Pan Z, Wu Y, Gu Z, Li M, et al. (2017) The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trail. Sci Rep 7(1): 575.
13. Cai B, Rajendran K, Bay BH, Lee J, Yen CC, et al. (2019) The Effects of a Functional Three-dimensional (3D) Printed Knee Joint Simulator in Improving Anatomical Spatial Knowledge. Anat Sci Educ 12(6): 610-618.
14. Bartikian M, Ferreira A, Gonçalves Ferreira A, Neto LL (2019) 3D printing anatomical models of head bones. Surg Radiol Anat 41(10): 1205-1209.
15. James M Otto, Nicolette S Birbara, Tarique Hussain, Gerald Greil, Thomas A, et al. (2017) Foley "3D printing from cardiovascular CT: a practical guide and review." Cardiovascular diagnosis and therapy 5: 507-526.

ISSN: 2574-1241

DOI: 10.26717/BJSTR.2023.52.008256

Arya Afzali. Biomed J Sci & Tech Res

This work is licensed under Creative *Commons* Attribution 4.0 License

Submission Link: https://biomedres.us/submit-manuscript.php

Assets of Publishing with us

- Global archiving of articles
- Immediate, unrestricted online access
- Rigorous Peer Review Process
- Authors Retain Copyrights
- Unique DOI for all articles

https://biomedres.us/