3D printed anatomical models allowing for customization: A new approach with potential advantages over computed tomography based models and cadavers

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INTRODUCTION

- With advances in technology and the high costs of purchasing yearly cadavers, medical educators have looked for other methods of anatomical education to supplement the usage of cadavers.[1]
- Studies have shown that 3D visualization methods can be 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]
- Many studies have been conducted in the past few years testing the efficacy of 3D printing in medical anatomy classes.[4-14] These studies have confirmed that 3D printed models improve knowledge and learner satisfaction in comparison with didactics that do not utilize models.
- 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. Otton et al found that arterial motion during a CT scan caused vessels to appear bigger than they actually were.[15]
- The challenges posed by using a CT scan to create a 3D model 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 are able to create custom models that isolate structures of interest within the human anatomy

- This approach sacrifices some accuracy in the portrayal of the actual structures by forgoing the use of CT data, but provides a simpler method of replicating gross anatomy for the purposes of medical student level learning.

OBJECTIVE

1. Repurpose artistically designed 3D files from third party developers to create anatomically correct representations of a human knee joint that can be easily customized prior to printing to include or exclude structures of interest.
2. Explore the capabilities of desktop stereolithography 3D printers to create multi-component anatomical models that incorporate soft and hard tissue structures made from flexible and inflexible resins.

METHODS

- An anatomically correct 3D file of a human leg complete with bone, musculature (later omitted for clarity), connective tissue, arterial/venous systems, nerves, and lymphatics (later omitted) was acquired from the online model marketplace Turbosquid and truncated via Blender to only include the knee joint and its main structures (Fig. 1).
- Each anatomical component surrounding the knee joint was rendered and exported individually and printed via the Formlabs 3B+ 3D printer through the PreForm 3D printing software using Elastic 50A/Flexible 80A for soft tissue structures and Formlabs Model Resin for bone to allow for maximal realism (Fig. 2,3,4).
- Our intention to assemble the knee as a multi-component model was replaced by printing the entirety of the knee and its significant structures as a one-piece print with Formlabs White V4 Resin, thereby enhancing the structural stability and durability of the model (Fig. 5,6,7,8).
- Additional models were customized via Blender to isolate the connective tissue structures of the proximal and distal aspects of the knee with emphasis on the junction between the femur and tibia (Fig 9,10,11,12).

RESULTS

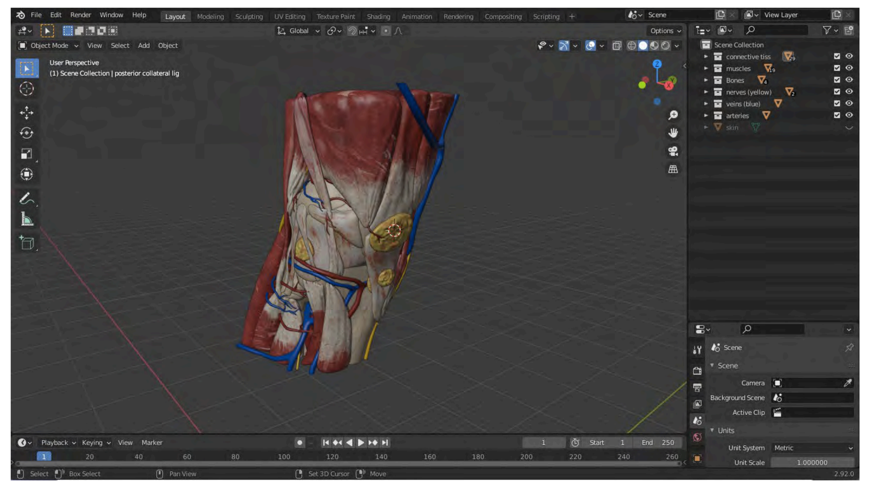

Figure 1: *Truncated knee model in Blender with 56 individually rendered anatomical structures.*

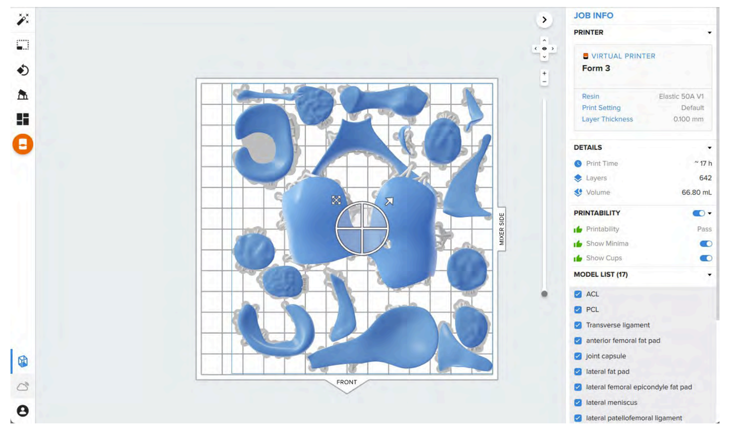

Figure 2: *Example of individually rendered connective tissue structures prepared for 3D printing in the 3D printing software PreForm.*

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

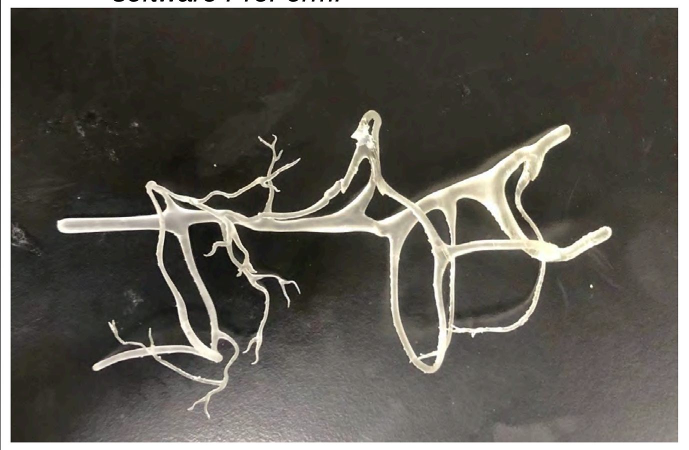

Figure 4: *Arterial system surrounding the knee joint printed in Elastic 50A Resin.*

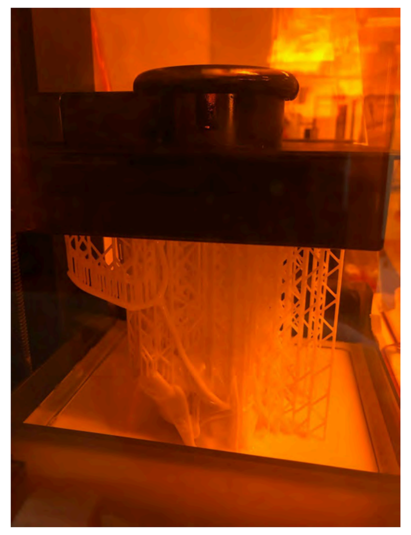

Figure 5: 3D printing the knee joint *(bones, connective tissue, arterial and venous systems, nerves) in Formlabs White V4 Resin.*

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

Figure 7: *Anterior view of 3D printed knee joint (bones, connective tissue, arterial and venous systems, nerves) in Formlabs White V4 Resin.*

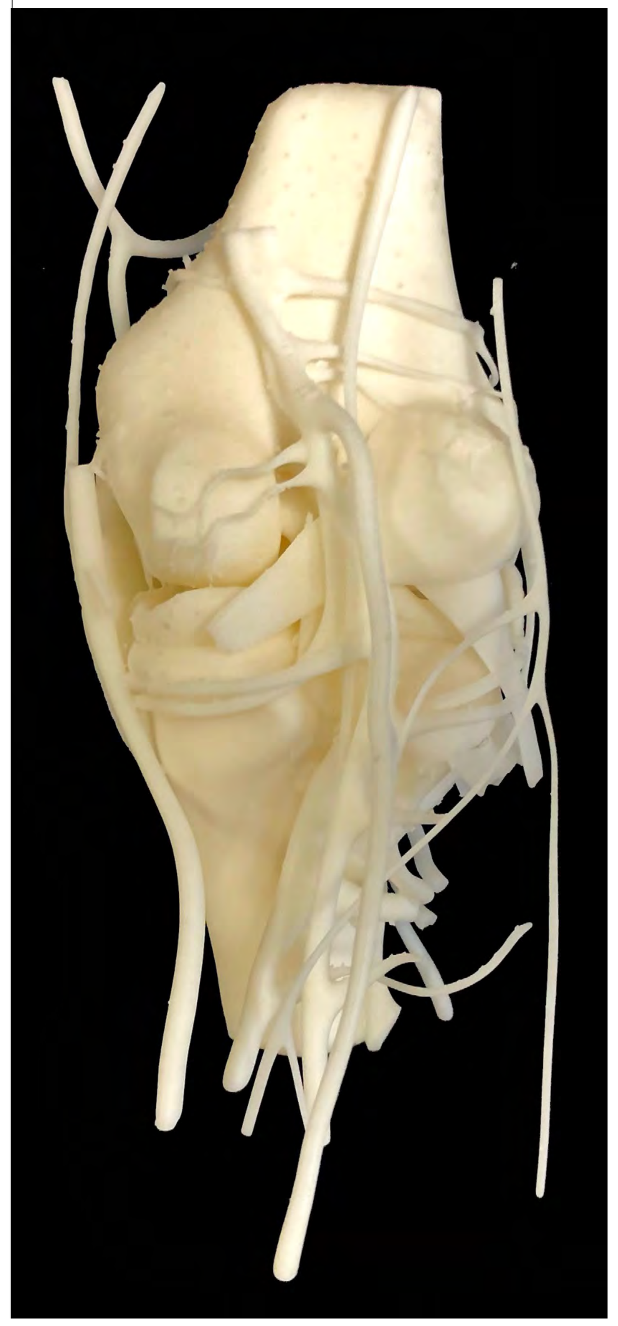

Figure 8: *Posterior view of 3D printed knee joint (bones, connective tissue, arterial and venous systems, nerves) in Formlabs White V4 Resin.*

RESULTS cont.

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

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

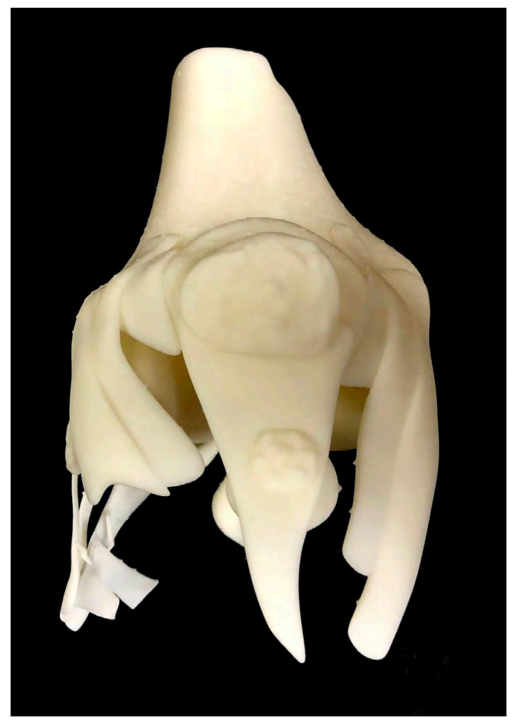

Figure 11: *Anterior view of femoral segment of knee joint (bones and connective tissue) in Formlabs White V4 Resin.*

Figure 12: *Inferior view of femoral segment of knee joint (bones and connective tissue) in Formlabs White V4 Resin.*

DISCUSSION/CONCLUSION

- 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 (11).
- 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 joint that has multiple layers of muscle, cartilage, arteriovenous system, and bursas.
- In this study we used an artistic rendering of a human knee to create a 3D model. This allowed for customization of the model 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.
- 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.
- With this future study, we hope to discover whether 3D anatomically correct artistic renderings could serve as a viable learning aid when compared to cadavers and 3D CT-based models.

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