

## **Comparison between Manual and Semi-Automated Modeling for the T12 Vertebra in 3D Slicer**

### **Abstract**

In this lab, the objective was to model the 12<sup>th</sup> thoracic vertebra (T12) for a client needing to address lower back pain. To model the vertebra, a software program known as 3D Slicer was used to import CT images of the patient and create layered sections of the T12. Using these sections, a 3D model was able to be created, which was fine-tuned using features such as paint, erase, and smooth. Once the model was complete, the volume of the model was determined. Additionally, a comparison between a manual modeling process and a semi-automated modeling process for the T12 vertebra was conducted. To do so, data was imported into MATLAB, where descriptive statistics were calculated and histograms, boxplots, and probability plots were made. It was observed that the manual modeling process had a higher mean and median volume, while also having less variance, indicating that the process was more consistent. The volume of the T12 vertebra modeled in this lab was 67463.18 mm<sup>3</sup>. This was within the standard deviation for the average volume of the semi-automated modeling process,  $64288 \pm 11378$  mm<sup>3</sup>, but not within the standard deviation for the average volume of the manual-modeling process,  $86907 \pm 5793.8$  mm<sup>3</sup>. Furthermore, the model included all of the important anatomical features such as the superior vertebral notch, spinous process, transverse process, vertebral body, vertebral foramen, and lamina. Ultimately, it was concluded that the manual modeling process was more consistent than the semi-automated modeling process and that the T12 vertebra modeled in this lab was more similar to the semi-automated process.

### **Introduction**

In this experiment, the goal was to act in place as a bioengineering student on co-op at a company that is responsible for designing custom orthopedic footwear. To create these designs, a modeling software known as 3D Slicer is utilized to model the necessary bones of the company's clients. 3D Slicer has a variety of features that allows it to be a great software for this purpose. In the software, computed

tomography (CT) and magnetic resonance imaging (MRI) files can be imported to help design models. Once these images are imported, a segment can be created of the desired bone. Then, an individual can manually model the bone using features such as paint, erase, and smoothing through the different views including axial, coronal, and sagittal.

Although, 3D Slicer's capabilities go far beyond manually creating models as its uses span across the medical field. In a study conducted by Fedorov et al., 3D Slicer's clinical applications are analyzed in depth.<sup>1</sup> The researchers discuss how 3D Slicer is an advanced image visualization workstation that supports many different types of imaging methods such as positron emission tomography (PET) and ultrasound. The platform can also be used to develop semi-automated medical image analysis tools as the software focuses on algorithm development. Furthermore, in a study conducted by Chen et al., the 3D Slicer software was used to automatically measure the morphological parameters of a portion of the femur.<sup>2</sup> The development of this system allows for orthopedic surgeons to have great assistance when given large dataset and promotes improved designs of knee prosthetics.

The specific task in this experiment is to model the 12<sup>th</sup> thoracic vertebra (T12) for a client that is dealing with lower back pain. The T12 vertebra is the lowest of the thoracic vertebra and is located above the lumbar vertebrae of the spine. In a study conducted by Chapman et al., it was hypothesized that T12 may be an important target for lower back pain.<sup>3</sup> The primary reasoning behind this is due to the afferent pathways from sensory neurons and innervation patterns in the low back.

Furthermore, this company is considering switching to a semi-automated modeling process. To decide whether this method is more precise and accurate than human modeling, a comparison between the manual modeling of team members will be compared to the semi-automated process for 50 trials. In this experiment, it is hypothesized that the semi-automated process will produce more consistent results. This is since the automation will reduce potential human error and will create a standard set of criteria to follow for each model. Additionally, the semi-automated process will most likely have more repeatable results as the computer is given the same instructions each time. In terms of the model that will be created

in this lab, it is hypothesized that it will be more similar to the manual results than the semi-automated results. It is more likely that the human error will lead it to be similar to the models created by other team members than a model made by the computer.

## **Materials and Methods**

### **Software Modeling**

To model the T12 vertebra, the imaging software 3D Slicer (version 5.61) was used. Prior to imaging, a folder of CT images was provided, which contained three different folders: Scouts, Axial Cap, and C. In this lab, the axial images were used specifically. Once images were downloaded, they were loaded into the software as DICOM data. In this database, the patient's name, study, and the Axial Cap was selected. Once the images were loaded in, the volumes module was selected, and Axial Cap was selected. In the active volume dropdown, CT-bones was selected as it provided the best contrast to view the spinal vertebrae. Afterwards, the segment editor module was selected, and in the master volume dropdown Axial Cap was selected. Then, using the threshold feature in the effects tab, all parts except the bone were excluded. Additionally, the axial, coronal, and sagittal views were adjusted to view the T12 vertebra. These values were -310.00mm, -62.65mm, and -7.70mm, respectively. Once the views were correctly adjusted, the apply button was selected, creating the first segment named "bones-general".

Next, a new segment was added, which was named "T-12 vertebra". Using the paint tool in the effects section, layers of the vertebra were painted using the axial view. The axial view was the optimal view as it provided a flat and easily viewable layer. The painting of the vertebra began at -330.0mm and continued up to -280.00mm. While painting, the zoom and pan features were utilized and paint brushes size was adjusted to allow for accurate painted sections. Once all sections were painted, the 3D view was shown in the upper right quadrant by selecting the "Show 3D" button. To easily view the vertebra on its own, the visibility of the "bones-general" segment was turned off. Then, using a reference model of the vertebra, the 3D model was adjusted using the paint, erase, and smoothing tools in the 3D quadrant.

Specially, paint and erase allowed for parts of the bone to be added or removed, while the smoothing tool allowed for the jagged edges and surfaces to be removed.

Once the model was complete, the segmentation module was chosen, allowing for the model's volume to be determined. In this module, the following selections were made, operation: export, output type: models, output node: export, and exported segments were set to visible. Then, the export button was selected, and the models module was chosen. In this module, the "T12-vertebra" segment was selected, and using the information menu, the volume of the model was determined. The segmentations module was then selected to export the model to an STL file. In this module, the "Export to Files" menu was expanded, where the reference volume was Axial Cap, the file format STL, the size scale 1.000, LPS as the coordinate system, and compression was disabled. Then, the file was exported and rendered into SOLIDWORKS for viewing.

### Statistical Analysis

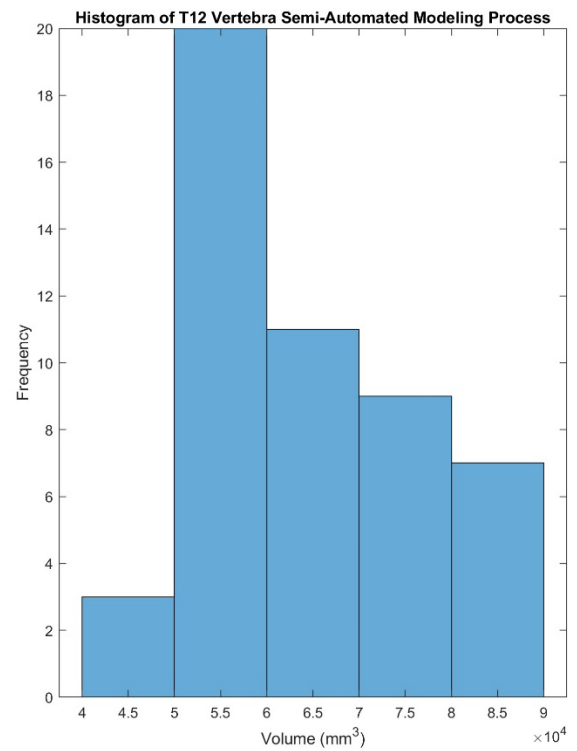
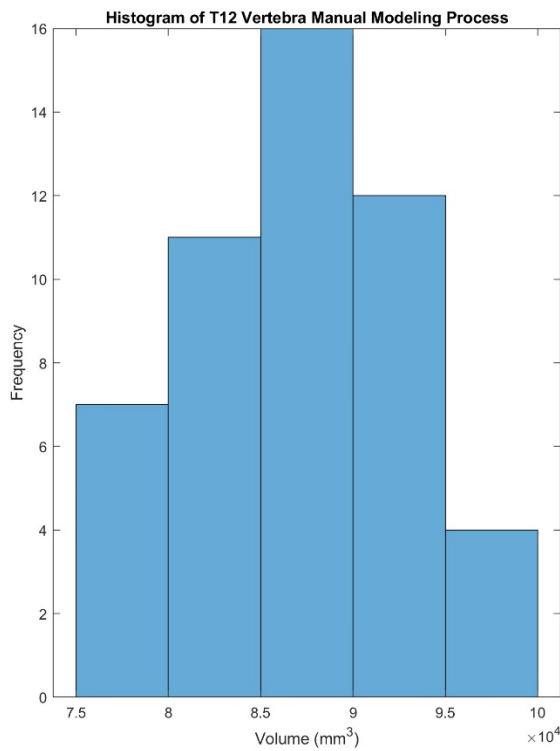
To compare the results between manual and semi-automated modeling processes for the T12 vertebra, a dataset containing volumes for both processes was imported into MATLAB (version R2023a). As the dataset was an Excel spreadsheet, the function `xlsread()` was used to import the data as a matrix. When analyzing the data for a specific process, the first column of the matrix was the manual process, while the second column was the semi-automated process. Then, descriptive statistics were found for each process, specifically the mean, median, and standard deviation. These statistics were found using `mean()`, `median()`, and `std()`, respectively. Additionally, histograms, boxplots, and probability plots were created as a means of visualizing the data using `histogram()`, `boxplot()`, and `probplot()` functions. While creating these figures, the `subplot()` function was utilized to allow for each process to be visually compared to the other on one figure.

## Results

| Modeling Method                       | Manual     | Semi-Automated |
|---------------------------------------|------------|----------------|
| Mean (mm <sup>3</sup> )               | 8.6907e+04 | 6.4288e+04     |
| Median (mm <sup>3</sup> )             | 8.6927e+04 | 6.1738e+04     |
| Standard Deviation (mm <sup>3</sup> ) | 5.7938e+03 | 1.1378e+04     |

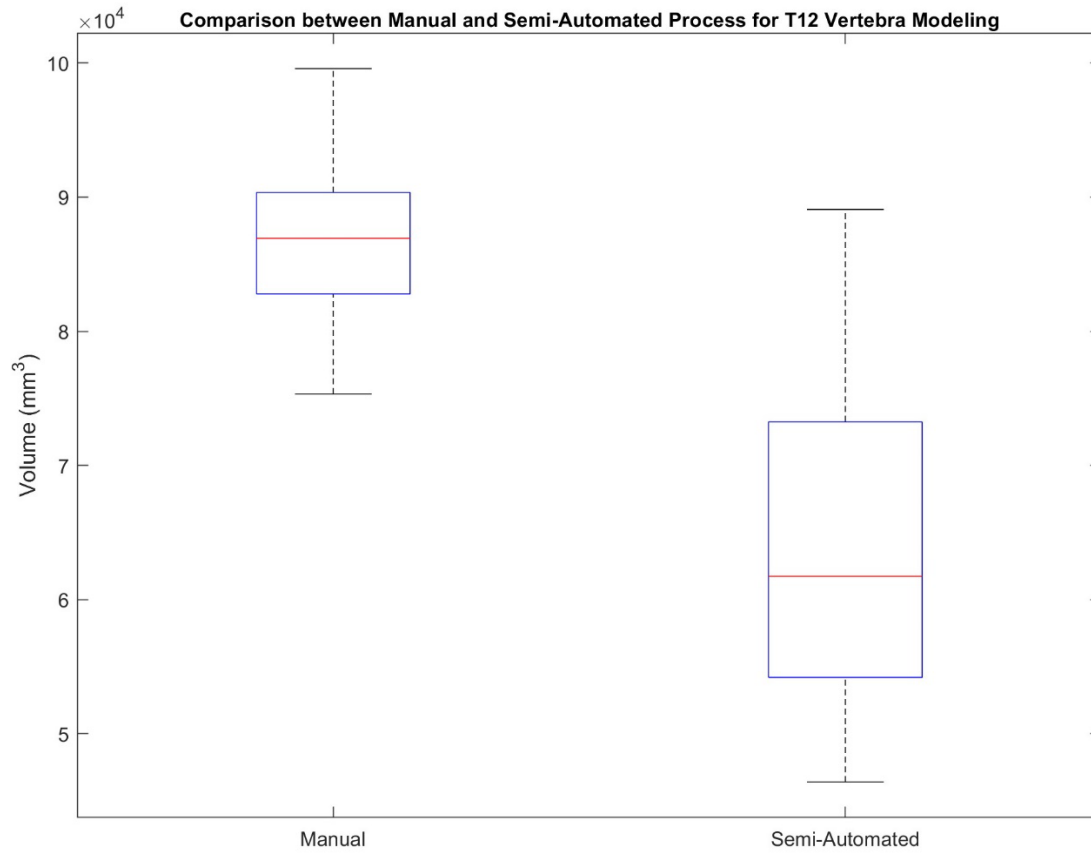
**Table 1:** Descriptive statistics for manual and semi-automated modeling processes for T12 vertebra.

In the comparison between the descriptive statistics for the manual and semi-automated modeling process, it is observed that both the mean and median volume are greater for the manual modeling method than the semi-automated modeling method (Table 1). Additionally, the standard deviation for the manual modeling process is less than the standard deviation for the semi-automated modeling process.



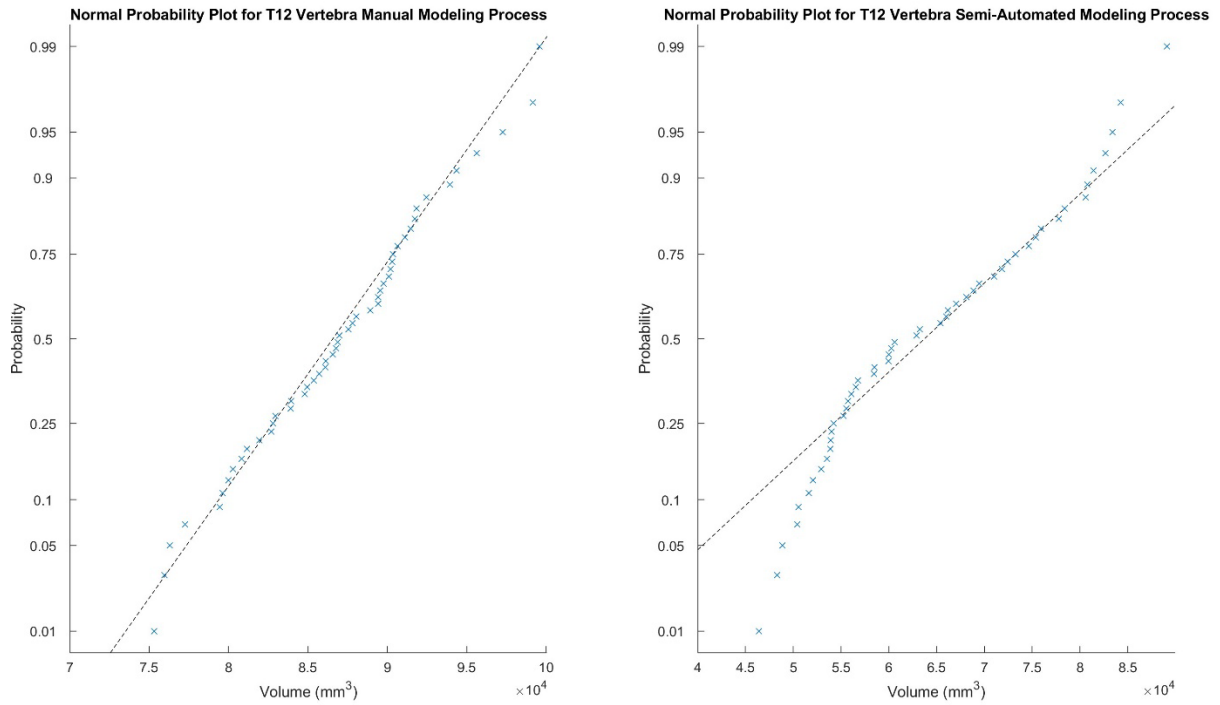
**Figure 1:** Histograms for manual and semi-automated T12 Vertebra volume data computed in MATLAB.

The histogram for the manual modeling process demonstrates a normal distribution (Figure 1). In this histogram, the highest frequency of volume measurements is concentrated in the middle and there is a similar number of bins on each side of the middle. On the other hand, the histogram for the semi-automated modeling process shows a distribution with a right skew (Figure 1) This can be observed as the highest frequency of volumes measurement is found within the lower volume bins.



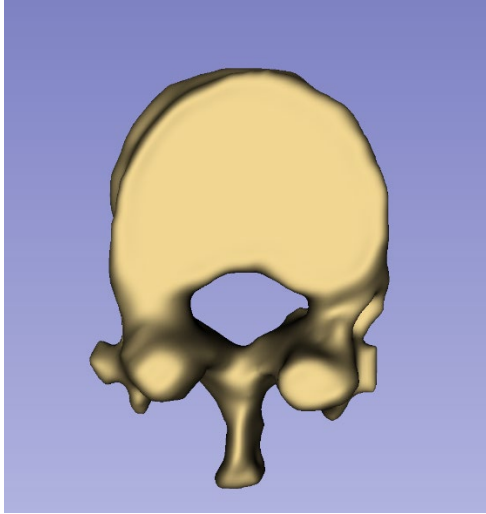
**Figure 2:** Boxplots for manual and semi-automated T12 Vertebra volume data computed in MATLAB.

The boxplot for the manual modeling process has a tighter interquartile range when compared to the boxplot for the semi-automated modeling process (Figure 2). Additionally, the median value is greater for the manual modeling process, which is consistent with the results in the descriptive statistics table (Table 1). Moreover, both boxplots do not contain any outliers, however, the range for the semi-automated modeling process is greater than the range for the manual modeling process.



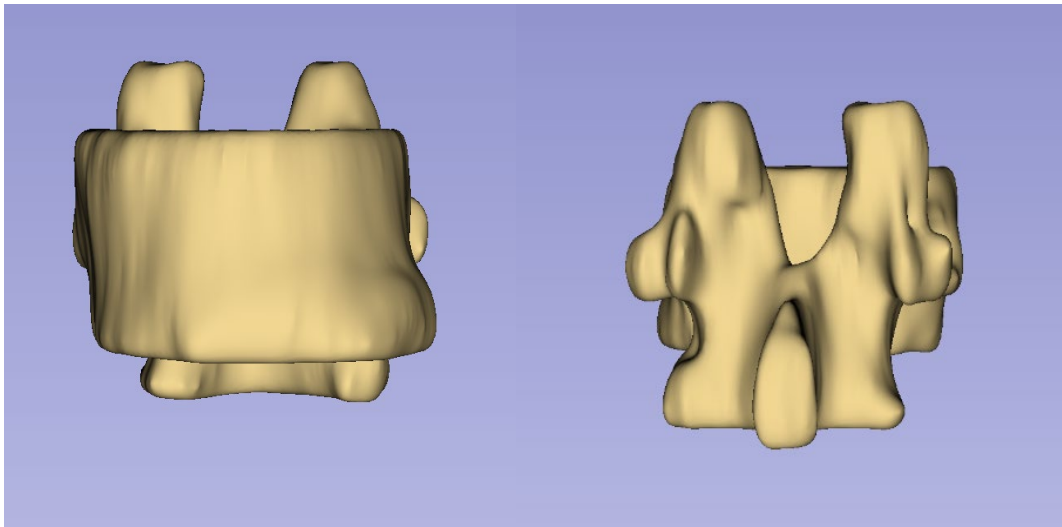
**Figure 3:** Normal distribution plots for manual and semi-automated T12 Vertebra volume data computed in MATLAB.

The probability plot for the manual modeling process demonstrates that a majority of the points closely align with the central line of distribution, indicating that a normal distribution is present, however the points deviate slightly at each tail (Figure 3). Similarly, the probability plot for the semi-automated process indicates a normal distribution of volume measurements, however, the tails skew significantly more than the manual modeling process (Figure 3).



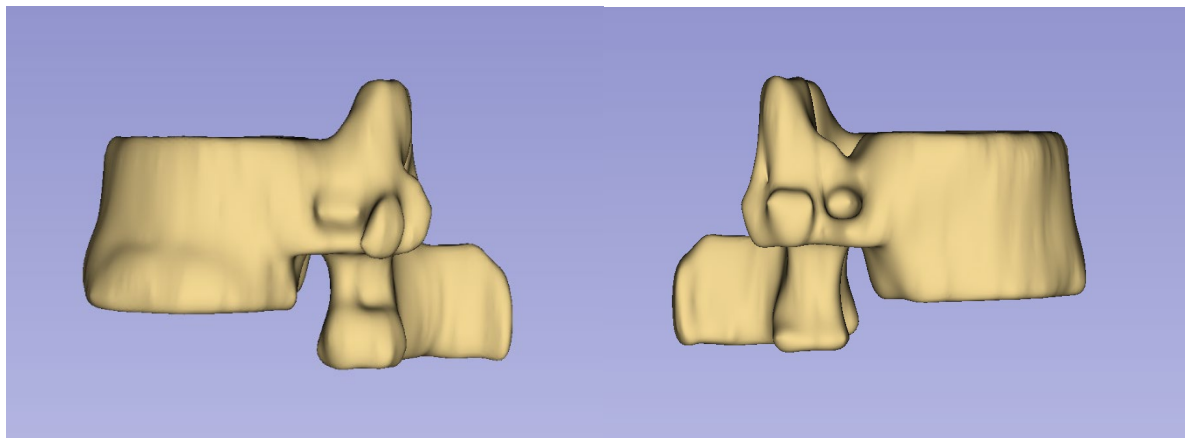
**Figure 4:** Sagittal view of T12 vertebra from top.

In Figure 4, the sagittal view of the T12 vertebra modeled in this lab is demonstrated. In this view, the vertebral body is extremely apparent, which is large round portion at the upper part of the vertebra. Additionally, in this figure, the vertebral foramen is also visible, which is the hole towards the middle of the vertebra. On the other end of the vertebral foramen, the spinous process is visible, and it extrudes out towards the bottom of the vertebra. Finally, the two circular structures towards the bottom of the vertebra are the superior articular processes.



**Figure 5a-b:** Coronal views of T12 vertebra from back (left) and front (right).

In Figures 5a and 5b, the two coronal views of the T12 vertebra are shown. In Figure 5a, the vertebral body is once again very evident. In this figure, the transverse process is also visible coming from the top of the vertebral body. In Figure 5b, there are more anatomical features that can be seen. For example, the spinous process is once again visible at the bottom of the vertebra. Additionally, the lamina can be seen, which are the flat bones that converge to connect with the spinous process. Moreover, both the superior and inferior articular processes are noticeable towards the top portion of the vertebra. Finally, a portion of the vertebral foramen, the large opening in the center, can be seen.



**Figure 6a-b:** Axial views of T12 vertebra from the left (left) and the right (right).

In Figure 6a and 6b, the two axial views of the T12 vertebra are shown, specifically from the left and the right. In both figures, the vertebral body is once again extremely evident. In these figures, the inferior vertebral notch is also visible. The inferior vertebral notch is the small space in between the spinous process and the vertebral process. Additionally, the lamina can be seen as the flat part of the spinous process. Finally, the transverse process can be seen protruding from the side. Ultimately, the T12 vertebra modeled in this lab has the main anatomical features of a T12 vertebra and the volume of this model was recorded as 67463.18 mm<sup>3</sup>.

## **Discussion**

The results of this study indicate several differences between manual modeling and semi-automated modeling processes for T12 vertebra. It was determined that the manual process yielded models with higher mean and median volumes and demonstrated a smaller standard deviation when compared to the semi-automated process (Table 1). Additionally, in terms of the boxplots, histograms, and probability plots created (Figures 1-3), it can be examined that the volumes for the semi-automated process skew more heavily. Specifically, the histogram for the semi-automated process demonstrates a right-skew of the data, while the probability plot demonstrates deviations at both tails. Moreover, the interquartile range in the boxplot of the semi-automated process is much larger than when compared to the interquartile range for the manual process. These results indicate the manual modeling process produces more consistent results compared to the semi-automated process.

The findings in this experiment do not support the initial hypothesis that semi-automated modeling process is more consistent than the manual modeling process. This is extremely intriguing as it was initially perceived that the semi-automated process would allow for more repeatability in modeling as the process is standardized by a set criterion. The manual process may be more consistent as it allows for the modeler to make real-time adjustments based off their prior experiences, which the semi-automated process may not be able to fully replicate. In short, the manual modeler is able to provide a nuanced approach to the model that a computer cannot. While the semi-automated process may not have been more consistent in this study, adjustments can be made to process to further optimize it for 3D modeling.

Additionally, in this study, a T12 vertebra was modeled by a bioengineering student. It was determined that the final volume of this model was  $67463.18 \text{ mm}^3$ . This was within the standard deviation for the average volume of the semi-automated modeling process,  $64288 \pm 11378 \text{ mm}^3$ , but not within the standard deviation for the average volume of the manual modeling process,  $86907 \pm 5793.8 \text{ mm}^3$ . Once again, this result was unexpected and did not support the initial hypothesis that the user-generated model would be more consistent with the models made through the manual modeling process.

One justification for the observed difference may be that the model created is missing features or has extra features. Using the sagittal, coronal, and axial views, it was determined that the model created in this study had the following features: superior vertebral notch, spinous process, transverse process, vertebral body, vertebral foramen, and lamina. While it appears that all features of the T12 vertebra are present, some of the features are modeled slightly inaccurately. For example, both the transverse process and the spinous process seem to be modeled smaller when compared to a true model of the T12 vertebra.<sup>4</sup> Additionally, it also appears that the space known as the vertebral foramen is larger in the true model than the model created. These inconsistencies may have accounted for the difference in volume, resulting in the value not being in statistical proximity of the other manually modeled vertebrae. Moreover, the student who modeled the vertebra featured in this study had no prior knowledge of 3D Slicer. Therefore, mistakes due to human error may have been made during the modeling process due to a lack of knowledge of the software's features.

## **Conclusion**

In this experiment, the objective was to model the 12<sup>th</sup> thoracic vertebra (T12) using the 3D Slicer modeling software. Additionally, in this study, a comparison was conducted between a manual and semi-automated modeling process for the vertebra. It was found that the manual modeling process yields more consistent results, suggesting that the semi-automated technology is not yet ready to be used in the medical field. Furthermore, it was determined that the model created by the user in this experiment was more similar to the models created by the semi-automated process. This finding was surprising and suggests that there were features inconsistencies with the model created, affecting the model's volume.

In the future, this study can be expanded in several ways to further the difference between these modeling processes. To begin, more trials can be conducted to gather a larger dataset to further support the results found in this experiment. The trials can also be conducted on other bones in the human body, such as other thoracic or lumbar vertebrae. Additionally, the semi-automated process can be optimized to produce more precise, consistent, and accurate modeling results.

## **References**

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