# Segmentation of Cortical and Cancellous Bone with Osteogenesis Imperfecta using Thresholding-based Method

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**Abstract.** Osteogenesis Imperfecta (OI) is a genetic bone disorders that mainly affect the bones which commonly leads to the multiple fractures. The purpose of this study is to segment the cortical and cancellous bone of tibia affected with the OI from the CT images. This project consists of two sections, segmentation of the cortical and cancellous bone, and the evaluation of the image performance. Contrast adjustment was implemented to enhance the contrast of images. K-Means and multi-threshold were implemented to segment the cortical bone at the proximal, diaphysis, and distal tibia. Post-processing was applied to further refine the segmented images. All segmented images were then evaluated by using the ground truth images. From the results, the process with contrast adjustment and multi-threshold obtained the highest accuracy and Dice-coefficient of 99.91% and 81.42% respectively at the proximal region while 99.93% and 73.88% at the distal region. However, pathway that make use of K-Means performed best in diaphysis region. This method has obtained the highest accuracy and Dice-coefficient of 99.98% and 95.59% respectively.

## 1. Introduction

Osteogenesis Imperfecta (OI) is a type of genetic bone disorder where the bones break or fracture easily by means of fragile bone [1]. It is estimated to happen in one per 30,000 of live births. OI is caused by the mutation of type 1 collagen genes (COL1A1 and COL1A2) [2]. Multiple fracture is the most common symptom for this disease. Prediction of the bone fracture become the main issue for this disease to determine the maximum force that the bone can withstand. Hence, segmentation of cortical and cancellous bone of tibia from CT images have become an important step for the purpose of reconstruct the bone which can be used in the prediction of the fracture risk [3–5].

Sahama et al. and Mansor et al. [6,7] implemented multi-threshold method, Canny edge detection, and single threshold in the segmentation of long bone with different threshold levels for proximal, diaphysis, and distal region. Threshold-based method is considered as the easiest way in the perform the image segmentation. Multi-threshold obtained the highest accuracy compared to Canny edge detection and single threshold old. Clustering method is one of the unsupervised process that grouping a set of similar objects in the same cluster or by means of separated into uniform groups. A comparison between the K-means and Fuzzy C-Means based on clustering accuracy for different shaped of clustered structures where there are in regular or irregularly scattered has been proposed by Çebeci et al. [8]. In
this study, image processing techniques were applied on the CT images of the tibia to segment the cortical and cancellous bone. The segmentation of the image was challenging due to the abnormal shape of type III OI bone. The approach includes pre-processing of the image to enhance the image, segmentation of the images using different techniques, and post-processing of the image for further refinement.

2. Methodology
The 388 CT images of type III OI tibia were obtained from Hospital Universiti Sains Malaysia (HUSM) with patient consent. Out of 388 tibia images, 31 are proximal, 330 are diaphysis, and 27 are distal tibia. Each slice of image has a dimension of 512 × 512.

2.1. Segmentation of Cortical Bone at Proximal, Diaphysis and Distal Region
There were two pathways implemented to segment the cortical bone. One includes with the pre-processing stage before segmentation while another path excludes the pre-processing stage. Figure 1 and Figure 2 show the summary of the pathways.

2.1.1. Overview of Pathway 1

![Figure 1. Block diagram of Pathway 1](image)

The intensity values of the image are adjusted to increase the contrast of the image especially between the cortical bone and the soft tissues. The bright areas appear brighter and conversely the dark areas appear darker. Unsharp masking was applied to enhance the edge details. Multi-threshold method was applied in the segmentation process to separate the interest region into foreground while unwanted image become the background. The output of the multi-threshold was set into binary.

2.1.2. Overview of Pathway 2

![Figure 2. Block diagram of Pathway 2](image)

The image was clustered into few groups according to the selected centroids of the clusters. Euclidean distance was used to assign the object to the closest cluster center and recalculated until there is no changes for the centroids. \( j \) is the objective function, \( k \) is the number of clusters, \( x \) is the number of cases, \( c_j \) is the centroid for the cluster \( j \). Equation (1) shows the function of K-Means.

\[
j = \sum_{j=1}^{k} \sum_{i=1}^{x} \left| x_i^{(j)} - c_j \right|^2
\]

(1)

The output image of K-Means is in grayscale form. The images were then grouped based on the intensity value of the region of interest into foreground (one) while the unwanted regions are grouped together into background (zero).

2.2. Post-processing in Pathway 1 and 2
There were two methods of post-processing, the first method was used for the cortical bone at proximal and distal regions while the second method was applied for the diaphysis region of tibia. This approach was taken address the different of bone thickness where the cortical bone at proximal and distal regions
is thinner than the cortical bone at the diaphysis region. The illustration of the methods is shown in Figure 3 and Figure 4.

2.2.1. Post-processing for Proximal and Distal Region of Tibia

![Post-processing for Proximal and Distal Region of Tibia](image)

Figure 3. Summary of post-processing in proximal and distal region

After segmentation process, there were still some unwanted small pixel regions around of inside the cortical bone. It was necessary to remove the small pixel regions and extract the cortical where the cortical had the largest area compared to other small areas. The cortical at proximal and distal region had almost similar intensity values as the soft tissue, thus, some of the cortical that had been extracted often face issues of incomplete boundary. Hence, edge linking process was performed to connect the endpoint of the broken boundary. Since the cortical bone at the proximal and distal region were thinner compared to the diaphysis region, therefore, morphological operation was applied to obtain the thickness that almost similar with the original grayscale image. There were few steps used in morphological operation:

i) The completed boundary of the cortical is filled, then the boundary of the filled region is extracted.

ii) The filled region of the cortical bone undergo erosion, then the boundary after erosion is extracted.

iii) The boundary extracted in step (i) combined with the boundary extracted in step (ii).

2.2.2. Post-processing for Diaphysis Region of Tibia

![Post-processing for Diaphysis Region of Tibia](image)

Figure 4. Summary of post-processing in diaphysis region

The output of the segmentation for diaphysis region consists of the tibia with fibula. In order to remove the unwanted region, fibula was labelled. Output of the labelled fibula was matched with the output of segmentation. The pixels with the same intensity value of 1 between labelled fibula with the output of segmentation was set as background (0) while the unmatched pixels were set as foreground (1).

2.3. Whole Tibia and Segmentation of Cancellous Bone

Since the cancellous bone is bounded by cortical bone, this indicates that the center region of the cortical segmented was considered as the cancellous bone. In order to segment the cancellous bone as foreground while other parts include cortical as the background, region filling was first applied to the segmented cortical. This results in the formation of whole bone region of tibia. The output of the region filling is matched with the cortical segmented. Both images with the same intensity value of 1 was set to 0 while the unmatched pixel was set to 1.

2.4. Image Validation

The performance of image segmented was then evaluated by comparing with the ground truth image. In this study, ground truth images were created manually by using GIMP software. Evaluation techniques includes sensitivity, specificity, accuracy, and Dice-Coefficient which based on the confusion matrix. The terms that associated with the confusion matrix are True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN).
Dice-Coefficient is one of the similarities measures used to calculate the similarities and variation between the output image segmented and ground truth image. Sensitivity is used to measure the positive pixels in the ground truth that are also identified as positive by the result of segmented image. Specificity used to measure the negative pixels in the ground truth that are also identified as the negative in the segmented image. Accuracy is the number of correct predictions made by overall of the predictions made. Equation (2), (3), (4) and (5) shows the calculation of Dice-Coefficient, Sensitivity, Specificity and Accuracy.

\[
\text{Dice} = \frac{2TP}{2TP + FP + FN} 
\]

\[
\text{Sensitivity} = \frac{TPR = TP}{TP + FN} 
\]

\[
\text{Specificity} = \frac{TNR = TN}{TN + FP} 
\]

\[
\text{Accuracy} = \frac{(TP + TN)}{(TP + TN + FP + FN)} 
\]

3. Results and Discussion

3.1. Segmentation of Cortical Bone

Both examples of process outputs for first and second pathway are shown in Figure 5 and Figure 6. Two pathways were used to segment the cortical bone at the proximal, diaphysis, and distal region of tibia.

The results of segmented cortical for each proximal, diaphysis, and distal region were almost similar in shape and thickness. There were only differences in some small region of white pixels. In order to compare the results, evaluation was carried out by using the ground truth images. Table 1 shows the average results for both pathways at different regions of tibia.
First pathway performed the best in proximal and distal regions while second pathway provide a better result than first pathway at the diaphysis region. Both accuracy and specificity obtained results with 99% or almost perfect. However, the similarity that obtained at the proximal and distal region were lower compared to the diaphysis region. Since the cortical bone at the proximal and distal regions are much thinner compared to the diaphysis region and has almost same intensity as the soft tissue that located around the cortical bone, it was easily to cause incomplete boundary upon segmentation. Hence, pre-processing was applied to the image to enhance the contrast between the cortical bone and surrounding soft tissues. The second pathway without the pre-processing stage obtained the highest similarity at the diaphysis region compared to the proximal and distal regions. This is because the contrast between the cortical bone and the soft tissue is very good compared to other regions of tibia. Hence, the first pathway with pre-processing stage that applied in diaphysis region caused some over-enhanced which would affect the similarity of the cortical segmented. The segment size directly affects the Dice-coefficient. The smaller the segment size, the higher the sensibility of the image. It would be easily affected if one of the positive pixels of output image is unmatched to the ground truth image [9].

Table 1. Performance of segmented image of cortical bone

|              | Proximal | Diaphysis | Distal |
|--------------|----------|-----------|--------|
|              | Path 1   | Path 2    | Path 1 | Path 2 | Path 1 | Path 2 |
| Average Sensitivity | 0.8510   | 0.8412    | 0.8889 | 0.9840 | 0.7053 | 0.6290 |
| Average Specificity  | 0.9994   | 0.9994    | 1.0000 | 0.9999 | 0.9997 | 0.9996 |
| Average Accuracy     | 0.9991   | 0.9990    | 0.9998 | 0.9998 | 0.9993 | 0.9991 |
| Average Dice-Coefficient | 0.8142   | 0.8051    | 0.9320 | 0.9559 | 0.7388 | 0.6575 |

3.2. Whole Tibia and Segmentation of Cancellous Bone

First pathway performed the best in segmentation of cortical bone in proximal and distal regions. Thus, the output of this pathway was used to segment the cancellous bone. On the contrary, second pathway that obtained the highest accuracy in diaphysis region was implemented to segment the cancellous bone. It was challenging to segment the cancellous bone prior to cortical bone since the intensity of the cancellous bone was almost similar with the background intensity. Hence, the cortical was segmented first and then followed by the segmentation of cancellous bone. However, there was a limitation where the cortical bone must be successfully segmented with a complete boundary. Only then, one can apply the method of segmentation of cancellous bone that has been proposed earlier. The results of the performance were shown in Table 2.

Table 2. Performance of segmented image of whole tibia and cancellous bone

|              | Whole Tibia | Cancellous Bone |
|--------------|-------------|-----------------|
|              | Proximal    | Diaphysis | Distal | Proximal | Diaphysis | Distal |
| Average Sensitivity | 0.9994   | 0.9950    | 0.9990 | 0.9953  | 0.9255   | 0.9996 |
| Average Specificity  | 0.9995   | 0.9999    | 0.9997 | 0.9996  | 1.0000   | 0.9996 |
| Average Accuracy     | 0.9995   | 0.9999    | 0.9997 | 0.9995  | 0.9999   | 0.9996 |
| Average Dice-Coefficient | 0.9905  | 0.9836    | 0.9769 | 0.9901  | 0.9571   | 0.9588 |

In term of similarity, the segmented cancellous bone was better compared to the cortical bone. In term of sensitivity, the results for both cancellous and whole tibia were 90% and above. In term of specificity and accuracy, both segmented cancellous and whole tibia obtained 99%. This indicates that the segmentation algorithms were able to identify the region of interest correctly. From the results, it can be concluded that the methods of segmentation of cortical and cancellous bone performed well in this study.
3.3. 3D Reconstruction of Tibia

Figure 7 shows the 3D reconstruction of tibia by using the VOXELCON software. This model was reconstructed from a total of 388 cortical and cancellous images.

![Figure 7](image)

(a) Cortical bone model, (b) cancellous bone model and (c) Combination model

4. Conclusion

This study employs a total of 388 CT images of type III OI tibia. The cortical and cancellous bone that composed in the CT images were segmented successfully using the image processing techniques that proposed in this paper. Results that were obtained has proved the ability of the segmentation algorithms to separate the cortical and cancellous bone where it is important in reconstruction of the 3D bone model for the future analysis such as prediction of fracture risk or in the study of the mechanical stress distribution on the tibia that affected with OI.

Acknowledgement

The authors would like to acknowledge the support from the Fundamental Research Grant Scheme (FRGS) under a grant number of FRGS/1/2016/TK03/UNIMAP/02/6 from the Ministry of Education Malaysia.

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