

Spatial Distribution of Adipose Compartments Size, Shape and Orientation in a CT Breast Image of a Mastectomy Specimen

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Development of efficient clinical breast imaging system has become a major concern in medical imaging today. Recent advancement in 3D imaging has allowed detailed analysis of breast anatomic structures. To assist with preclinical validation of breast imaging systems, high resolution anthropomorphic software phantoms have been introduced [1]. The phantoms developed at the University of Pennsylvania and Delaware State University simulate the breast outline covered by a skin layer, and the breast interior matrix of Cooper's ligaments which define compartments filled with adipose or fibro-glandular (dense) tissue. The simulation algorithms require input parameters such as number of compartments, distribution, and size and shape of adipose compartments. To obtain more realistic phantoms, these simulation parameters should be inferred from clinical images. In this study, we have investigated the distribution and spatial placement of adipose compartments in reconstructed CT images of a mastectomy specimen.

An anonymized mastectomy specimen was donated to the University of Pennsylvania. The specimen was imaged on a whole body, multi-slice CT system (Sensation 64, Siemens Medical Solutions USA, Malvern, PA), using the following parameters- Tube Potential: 120 kVp, Tube Current: 400 mAs, Slice Thickness: 0.6 mm, Acquisition Protocol: Head, Exposure Time: 1000 msec, Focal Spot Size: 1.2 mm, and ROI size: 371mm-by-371mm (512-by-512 array of 0.72 mm-by-0.72 mm pixels). The adipose tissue compartments in the reconstructed high intensity CT slices were segmented manually using ITK-SNAP [2]. We segmented approximately 14% of phantom volume (most discernible adipose compartments) of 619 slices. The segmentation results (voxels corresponding to each compartment) were stored in VTK format (Kitware Inc., Clifton Park, NY). Each compartment was characterized by its volume and the coordinates of the barycenter. Subsequently, the moment of inertia tensor was calculated. An ellipsoid centered at the barycenter with the same moments of inertia as a compartment was determined [3]. The goodness of ellipsoidal fitting was assessed by Dice coefficients [3]. Fitted ellipsoids were characterized by the size and orientation (Euler's angle) of their semi-axes. The ellipsoid shapes were quantified by the ratio of the largest and the smallest semi-axes. Figure 1 shows the ellipsoidal fitting for the compartment with the highest dice score. We obtained Dice scores between 0.56 and 0.88 inclusive. The size of the adipose compartments ranged from 0.0652 cm³ to 3.97 cm³. We have observed a significant correlation between compartment sizes and the barycenter y-coordinate (p-value ≤ 0.02), but not with x- and z-coordinates (p-value >0.05). The ellipsoidal semi-axes ratios ranged between 1.24 and 6.70 inclusive (as shown in Figure 2), and were not correlated with the compartment sizes (p-value = 0.56). Further, there is no sufficient evidence to support hypothesis that the compartment orientations and positions are correlated (p-value >0.05).

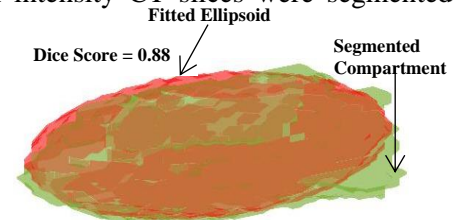


Figure 1: Ellipsoidal fitting of a compartment

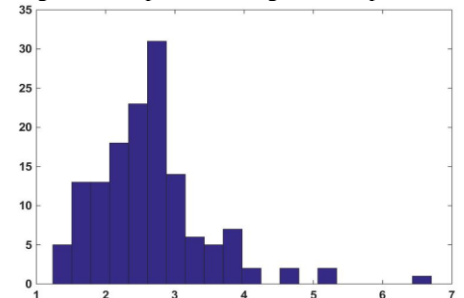


Figure 2: Histogram of shape ratio

We successfully demonstrated a proof of concept segmentation and ellipsoidal fitting of adipose compartments from CT images of a mastectomy specimen. The observed high Dice coefficients justified the use of fitted ellipsoids for characterization of the compartment size, shape, and orientation. The mastectomy specimen, after being detached from the body and fixed in formalin, doesn't fully reflect the real breast. Our future work would extend this analysis to clinical images of healthy breast anatomy. Further, potential development of automatic tissue segmentation would provide a more objective and accelerated analysis. Finally, a similar approach to the analysis of the size, shape and orientation may be developed for other 3D imaging modalities, to assist with parameter specification in anatomy and imaging simulation.

References:

1. David D. Pokrajac, Andrew D. A. Maidment, Predrag R. Bakic, Optimized generation of high resolution breast anthropomorphic software phantoms. *Med. Phys.* 2012 Apr; 39: 2290-2302.
2. Paul A. Yushkevich, Joseph Piven, Heather Cody Hazlett, Rachel Gimpel Smith, Sean Ho, James C. Gee, and Guido Gerig. User-guided 3D active contour segmentation of anatomical structures: Significantly improved efficiency and reliability. *Neuroimage* 2006 Jul 1;31(3):1116-28.
3. Francisco Contijoch, Jennifer M. Lynch, David D. Pokrajac, Andrew D.A. Maidment, and Predrag R. Bakic, Shape Analysis of Simulated Breast Anatomical Structures. *SPIE Medical Imaging* 2012.

Abstract

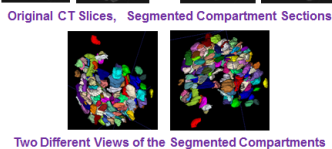
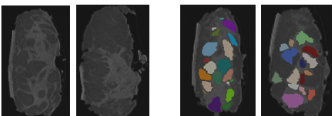
- High resolution anthropomorphic software phantoms have been developed to assist pre-clinical validation of breast imaging systems [1].
- The simulation algorithms require input parameters such as number of compartments, distribution, and size and shape of adipose compartments.
- To obtain more realistic phantoms the above parameters need to be inferred from clinical images.
- This work investigates the distribution and spatial placement of adipose compartments in reconstructed CT images of a Mastectomy Specimen.

CT Scanning Parameters

- Multi-slice CT system (Sensation 64, Siemens Medical Solutions USA, Malvern, PA).
- Tube Potential: 120 kVp.
- Tube Current: 400 mAs.
- Slice Thickness: 0.6 mm.
- In-slice Resolution: 0.72 mm x 0.72 mm.
- Acquisition Protocol: Head.
- Exposure Time: 1000 ms.
- Focal Spot Size: 1.2 mm.

Adipose Compartments Segmentation

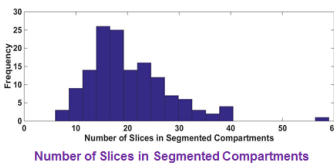
- The adipose tissue compartments in the reconstructed high intensity CT slices were segmented manually using ITK-SNAP [2].
- We segmented 142 adipose compartments from the 619 slices of the mastectomy specimen.
- The compartments span in 2883 segment slices in total and more than 20 slices on average.
- The segmented adipose tissue compartments covered approximately 14% volume of the total mastectomy specimen.



Ellipsoidal Fitting

- Each compartment was characterized by its volume and the coordinates of the barycenter.
- An ellipsoid centered at the barycenter with the same moments of inertia as a compartment was determined [3].
- The goodness of ellipsoidal fitting was assessed by Dice score measuring the overlapped volume between the fitted ellipsoid and each compartment.

$$\text{Dice Score} = \frac{2|\text{Ellipsoid} \cap \text{Compartment}|}{|\text{Ellipsoid}| + |\text{Compartment}|}$$

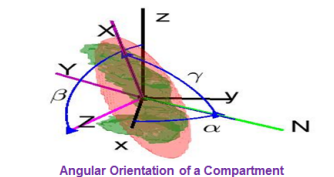


Size, Shape and Orientation Distribution

- Fitted ellipsoids were characterized by the size and orientation (Euler's angle) of their semi-axes.
- The ellipsoid shapes were quantified by the ratios of the largest and the smallest semi-axes.
- The sizes of the segmented compartments were measured by their volumes.
- The Adipose compartmental orientations were characterized by the Euler angles of the ellipsoid axes.
- The positions of the segmented compartments were determined by the coordinates of compartmental centers.

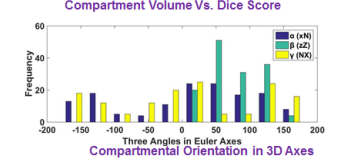
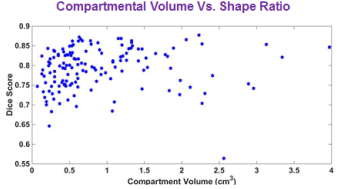
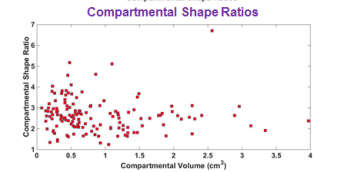
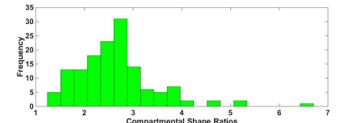
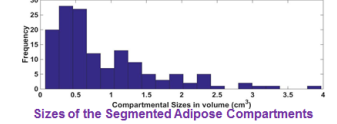


Ellipsoidal Fitting of Compartment with the Largest Dice Score (0.88)



Results and Discussion

- We observed a significant correlation between compartment sizes and the barycenter y-coordinate (p-value ≤ 0.02), but not with x- and z-coordinates (p-value > 0.05).
- The ellipsoidal semi-axes ratios ranged between 1.24 to 6.70 inclusive and were not correlated with the compartment sizes (p-value = 0.56).
- The compartmental orientations and positions were not correlated since the p-value (> 0.05) was not significant.



Extracted Parameters

Parameters	Ranges
# Compartment Slices	(6, 59)
Shape Ratio	(1.24, 6.70)
Size	(0.065, 3.97) cm ³
Compartmental Orientation	(-178, 178) deg (8, 161) deg (-178, 179) deg
Ellipsoidal Fitting Accuracy	(56, 88)%

Future Work

- Automatic segmentation of adipose compartments would be preferred to accelerate the analysis and reduce operator bias.
- The extracted shape parameters of the compartments may be utilized to inform the simulation.
- The shape analysis in this work could be used as a benchmark in extracting the compartment parameters from clinical breast images.

Conclusions

- We successfully demonstrated a Proof Of Concept for segmentation and ellipsoidal fitting of adipose compartments from CT images of a mastectomy specimen.
- Since the mastectomy specimen does not fully reflect the real breast, this analysis would be required for clinical images of Healthy Breast Anatomy.
- Further, potential development of automatic tissue segmentation would provide a more objective and accelerated analysis.
- Finally, a similar approach to the analysis of the size, shape and orientation may be developed for other 3D Imaging Modalities.

References

- David D. Pokrajac, Andrew D. A. Maidment, Predrag R. Bakic, Optimized generation of high resolution breast anthropomorphic software phantoms. Med Phys. 2012 Apr; 39(4): 2290-2302.
- Paul A. Yushkevich, Joseph Piven, Heather Cody Hazlett, Rachel Gimpel Smith, Sean Ho, James C. Gee, and Guido Gerig. User-guided 3D active contour segmentation of anatomical structures: Significantly improved efficiency and reliability. Neuroimage 2006 Jul 1;31(3):1116-28.
- Francisco Contijoch, Jennifer M. Lynch, David D. Pokrajac, Andrew D.A. Maidment, and Predrag R. Bakic, Shape Analysis of Simulated Breast Anatomical Structures. SPIE Medical Imaging 2012.

Acknowledgements

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