Parametric Analysis to Optimize Calculated Head Segment Mass and Center of Gravity

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INTRODUCTION

- Studies on biomechanics of the human body require body segment mass properties.
- Studies have previously used scales, custom designed support box, and commercial software to calculate center of gravity (CG) and head mass.[1,2,7]
- The main objectives of this study are to investigate an accurate and minimally invasive technique to calculate precise mass of body segments, and to quantify differences between the CG values calculated from a custom MATLAB code and the physical measures.
- Various Hounsfield units (HU) and densities derived from literature were used to decrease percent error when comparing physical head mass to calculated head mass.
- CG locations were calculated using the optimum parameters found from head mass.

MATERIALS & METHODS

- Physical head mass properties and CT scans from 25 post mortem human surrogates (PMHS) consisting of 10 males and 15 females were obtained from a previous study.[4]
- A custom MATLAB code was created to calculate numerical head mass values using CT images.
- Individual DICOM pixel resolution was used to calculate length and width (mm) of each voxel. The height of each voxel is determined by the slice thickness of each DICOM (mm).
- Head mass was calculated using the following equations:

(1) $V_{voxel} = l * w * h$

(2) $V_x = V_{voxel} * n_x,$

$\quad where\ n_x = number\ of\ voxels\ counted\ for\ bone\ or\ soft\ tissue$

(3) $M_x = V_x \times \rho$

(4) $M_{slice} = M_{bone} + M_{soft\ tissue}$

(5) $M_{head} = \sum_{k=1}^{n} M_{slice}, \quad where\ n = number\ of\ slices\ in\ CT\ scan$

- HU values from O'Flaherty (1991) and Yampri (2009) were tested with varying densities obtained from O'Flaherty and Tse (2014) to find the combination resulting in the lowest percent error when compared to the physical mass of the head.[5,6,5,3]

Table 1: Density and HU values used for soft tissue or bone showing optimized ranges (red)

	Density (g/cm^3)		HU Range	
	O'Flaherty	Tse	O'Flaherty	Yampri
Soft Tissue	1.00	1.04	-538 to 707	-200 to 400
Bone	1.92	1.21	708 to 3500	401 to 1800

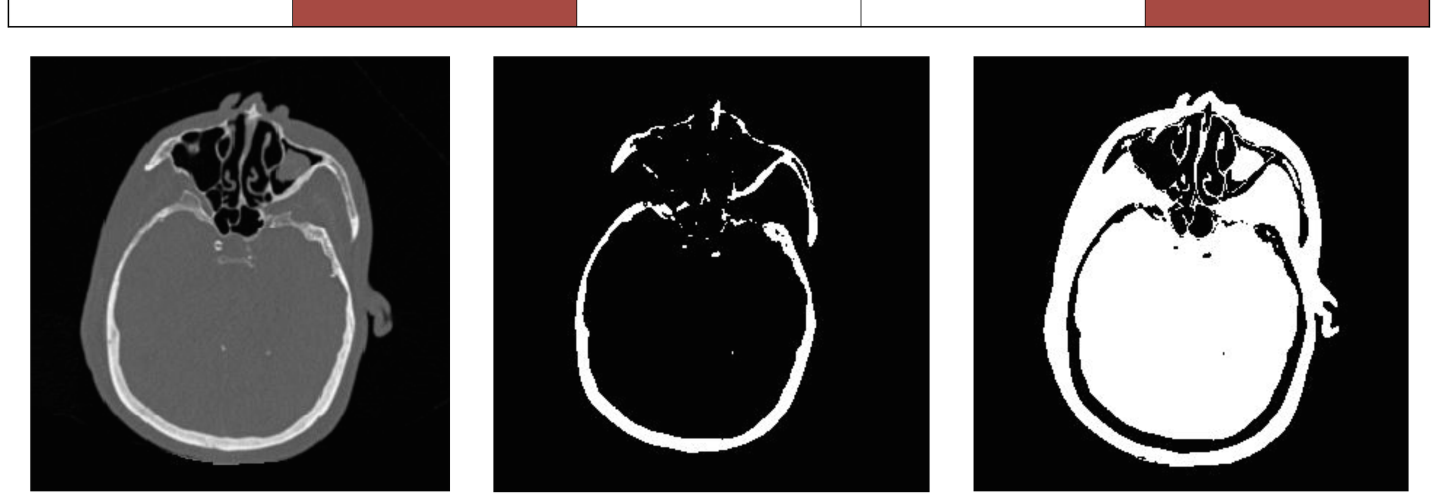


Figure 1: CT scans showing both soft tissue and bone, only bone, then only soft tissue

- MATLAB code was made to calculate CG using O'Flaherty densities, Yampri HU, and the following equation:

$$CG_C = \frac{\sum_{i=1}^{n}(C_{bone_i} * m_{bone_i} + C_{tissue_i} * m_{tissue_i})}{\sum_{i=1}^{n}(m_{bone_i} + m_{tissue_i})}$$

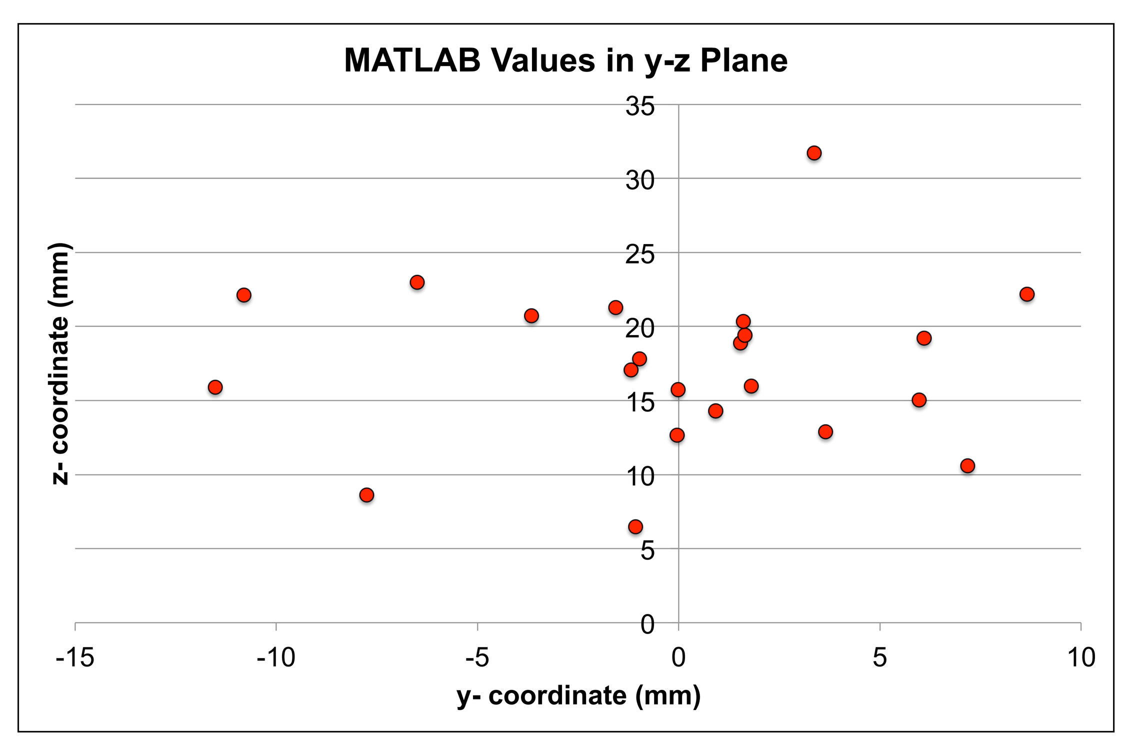
C: x, y, and z coordinates

RESULTS & DISCUSSION

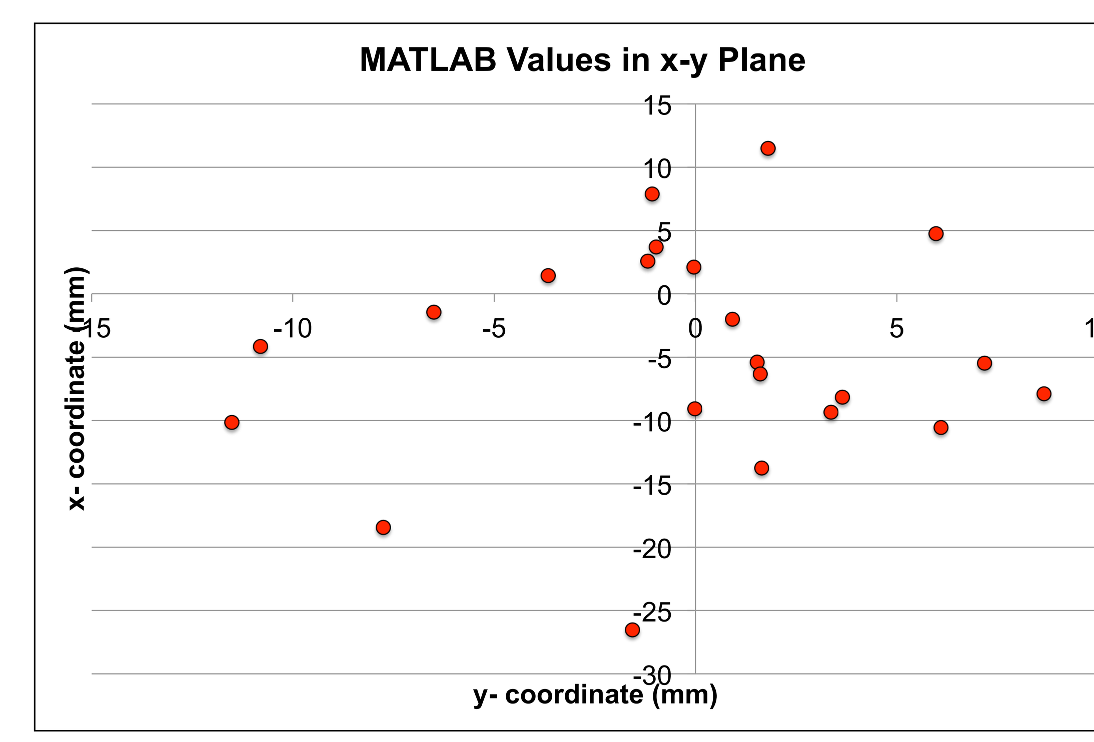
- Initial O'Flaherty HU values of -538 to 707 and 708 to 3500 combined with the O'Flaherty densities of 1.00 g/cm^3 for soft tissue and 1.92 g/cm^3 for bone resulted in a baseline percent error of 7.32%.[5]
- Yampri's HU values combined with O'Flaherty's density values of 1.00 g/cm^3 for soft tissue and 1.92 g/cm^3 for bone resulted in the lowest percent error of 4.29%.[6,5]
- All of the combinations tested lowered the percent error between the physical head mass and the mass from the CT analysis, with the lowest percent error resulting from using Yampri's HU and O'Flaherty's densities.[6,5]

Table 2: Resulting percent error from trials with optimized values in red

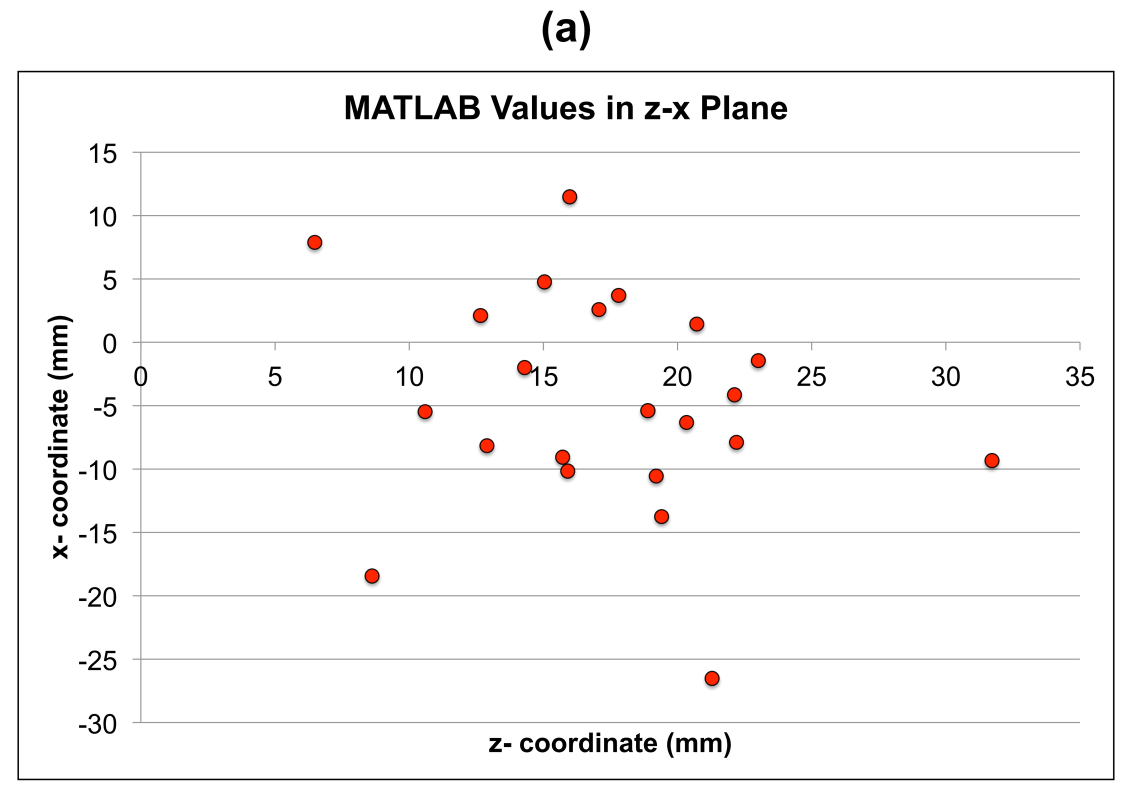
Density Values	HU	Male Percent Error (%)	Female Percent Error (%)	Percent Error (%)
O'Flaherty	O'Flaherty	5.49 ± 7.03	6.10 ± 9.17	7.32 ± 10.52
Tse	Yampri	5.70 ± 3.31	6.43 ± 4.07	6.14 ± 3.72
O'Flaherty	Yampri	4.13 ± 4.71	4.40 ± 6.57	4.29 ± 5.79
Tse	O'Flaherty	5.29 ± 5.10	4.60 ± 8.68	4.87 ± 7.34



(a)



(b)



(c)

Figure 2: Graphs representing difference between calculated CG and physical values

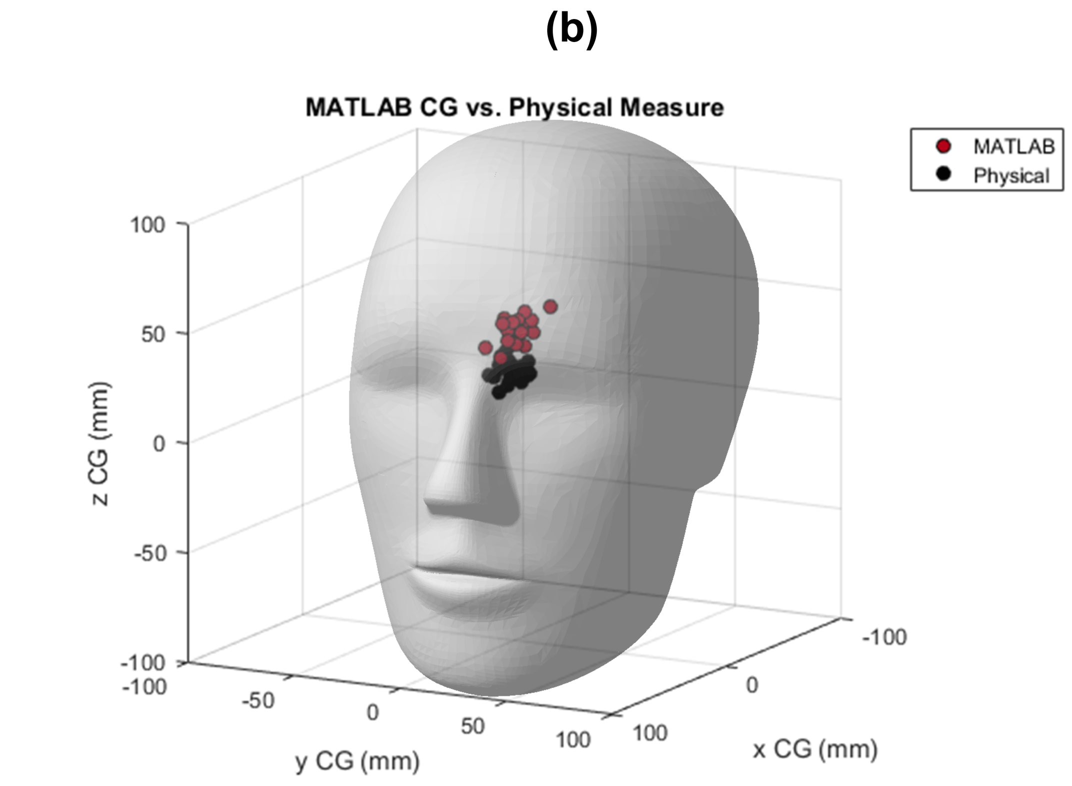


Figure 3: 3D plot showing (x,y,z) coordinates for CG with respect to HIII 50th head dimensions

- Average differences between the physical CG values and the MATLAB CG values were 4.77 mm in the x direction, 0.12 mm in the y direction, and -17.36 mm in the z direction.
- MATLAB CG values showed systematic error in z direction, and random error in x and y directions.
- Study used 22 of the 25 original subjects in sample due to eliminating factors.
- Limitations:
  - →CT scans were completed on two different scanners (Siemens and GE), which could cause variability between grey scale values in scans.
  - →Human error from CG physical values being measured using FARO arm and CG MATLAB coordinates being selected from Osirix.
  - →Coordinate system transformation errors between physical, MATLAB, and Osirix.

CONCLUSIONS

- CT scans provide researchers with a minimally invasive technique that could potentially measure accurate body segment masses of live subjects.
- These results are beneficial for biomechanics studies that will require dynamics analysis of human subjects.
- Percent error of calculated head mass compared to physical mass had a 41.4% reduction when density values and HU were changed from the initial literature values.
- Future work could optimize densities and HU to further decrease percent error between physical mass and calculated value, and between calculated CG and physical measure.

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