# Accuracy of Rapid Prototype Models for Head and Neck Reconstruction

Gerald T. Grant, CAPT, DC, USN, Shayne Kondor, MSAE, Robert M. Taft, CAPT, DC, USN,
Naval Postgraduate Dental School, Navy Medicine Professional Development Center, Bethesda, MD

## Objective

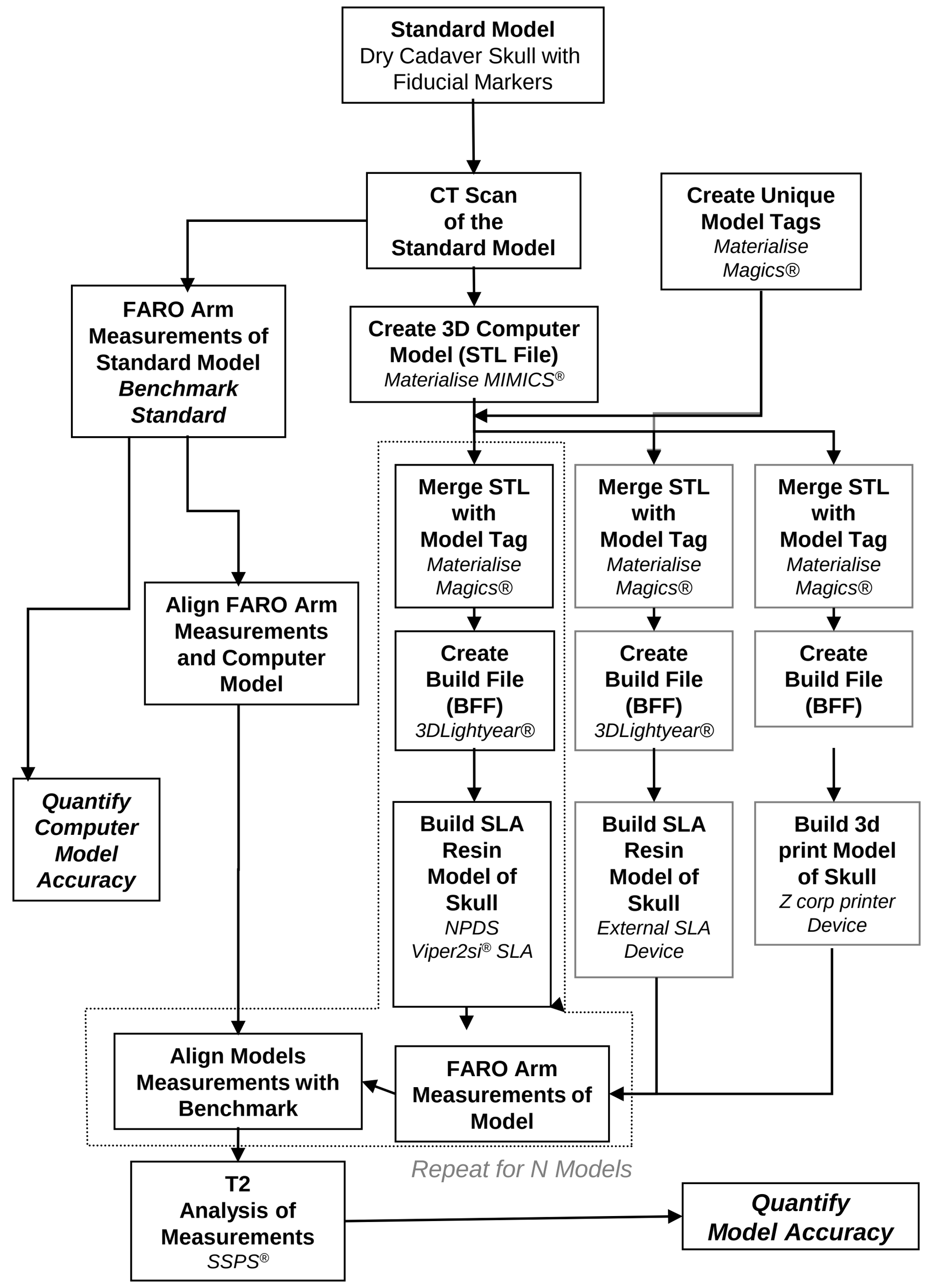
The purpose of this study was to assess the accuracy of Medical models, by validating the accuracy of Additive manufactured skull models with a coordinate measurement device .

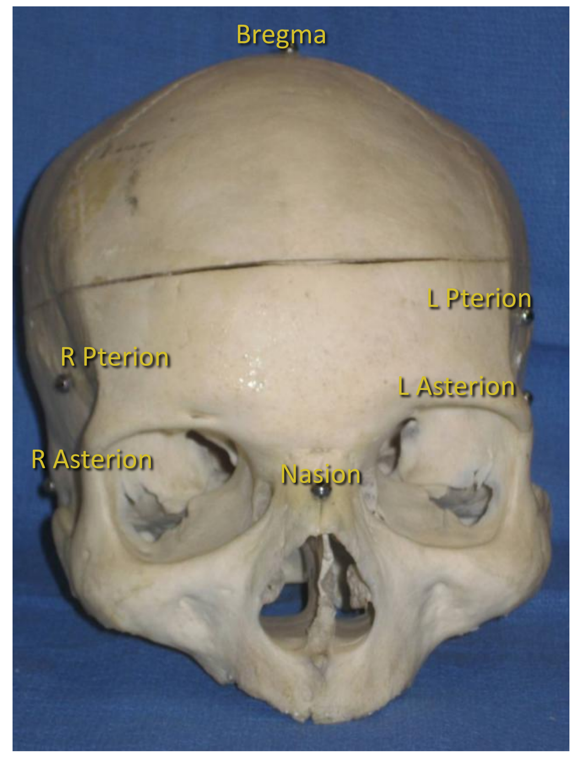
## Background

The use of medical models in surgical treatment planning and the fabrication of surgical guides is becoming more common. Medical DICOM images generally CT and MRI are converted to 3D computer models for to fabricate physical models form additive manufacturing techniques. However, there are few objective validation studies of the accuracy between the original image, the computer 3D interpolation, and the resultant models. Most published studies relied on an observer measuring anatomical landmarks point to point on the Image and the Computer design and correlating them with the associated landmarks on the manufactured model using calipers. Geometric dimensioning and tolerance (GD&T) techniques are used in the manufacturing industry for quality control of precision parts using a coordinate measurement device (CMD). This precision part inspection approach appears ideal to assess the accuracy of RP models against the original scanned source, and could be used as the standard for quality assurance of model accuracy.

## Materials and Methods

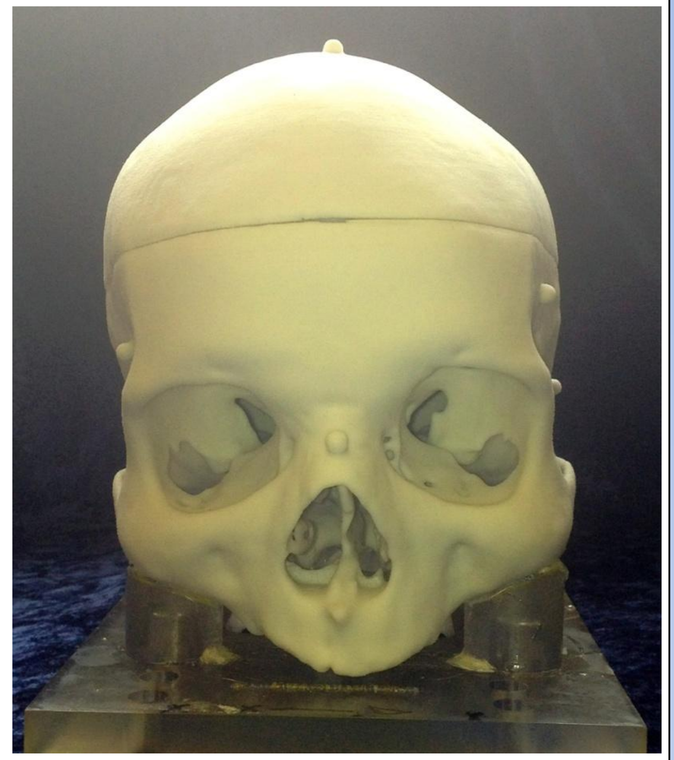
A human skull with eight 5mm sphere fiducial markers was measured with a CMD on a custom index. All markers were measured from an origin (the fiducial at the anatomical Sella) and Scanned on a MDCT scanner. STL files were developed from the scan and 7 models each were fabricated using a VIPER SLA as a pilot group, then 7 for the 7000 SLA, (resin) and Z corps printer (gypsum/binder). Each model was built with the same build set-up along with validation coupons and identification tags. After the appropriate post-cure, each model was measured in the same manner as the Standard. A Euler Angel Rotation to align the coordinate axis of the standard and the model was used to account for discrepancies in model placement for measurement. Data was collected using the absolute difference in the measurements of the Standard to the fabricated model.




Standard Model

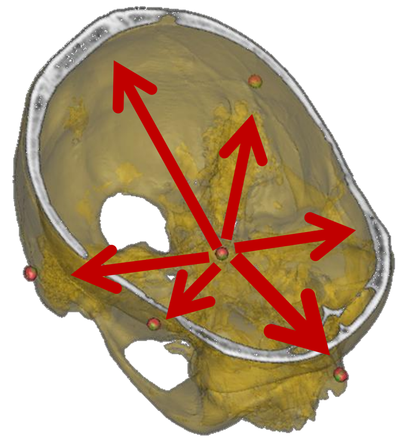
SLA Model

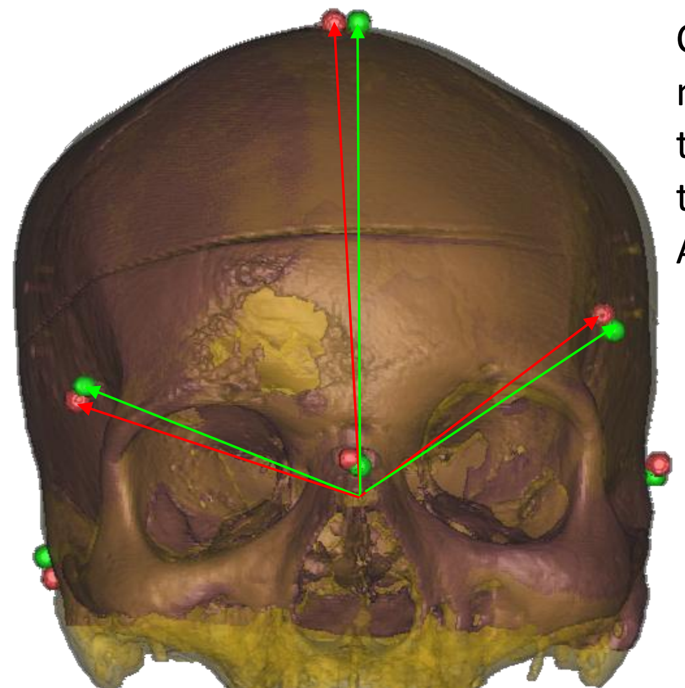


Print Model

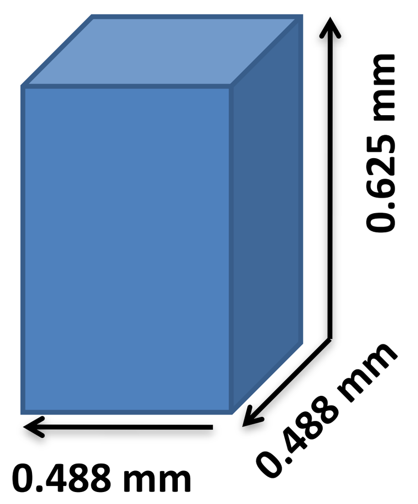
Coordinate Measurement Device used to measure the distance of the Fiducial markers from the origin. Multiple contacts made on each fiducial to calculate the center of the sphere

Measurements are made from the origin point (*sella*) to the outlying markers





Comparison of the coordinate measurements of the standard to the printed model prior to the Euler Angle Rotation to Align Coordinate Axes




Voxel measurements for MDCT scans are orthotropic in nature to account for volume within the x, y and z axis.

## Results

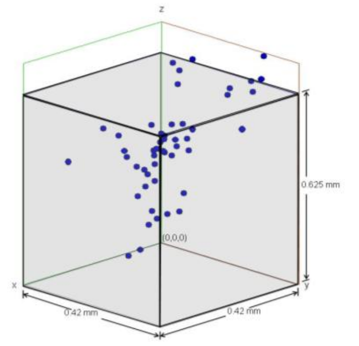
| | | Difference from Standard Transformed Coordinates | | | *Deviations along X, Y, or Z axes are reported in mm. | | |
|---|---|---|---|---|---|---|---|
| | *L Asterion** | *L Pterion** | *Nasion* | *R Pterion** | *R Asterion** | *Bregma* | *Lambda* |
| *C1* '\|DX\| | 0.223750738 | 0.11883577 | 0.028685459 | 0.184461822 | 0.04324168 | 0.015057642 | 0.06510784 |
| \|DY\| | 0.20704766 | 0.09304451 | 0.23355934 | 0.0763764 | 0.0508136 | 0.026593082 | 0.04175208 |
| \|DZ\| | 0.38083845 | 0.47524457 | 0.57148626 | 0.41726873 | 0.37125004 | 0.388691576 | 0.20813036 |
| *C2'*\|DX\| | 0.202183728 | 0.07257891 | 0.007227445 | 0.169506845 | 0.01163506 | 0.01552265 | 0.07890042 |
| \|DY\| | 0.25053387 | 0.108986134 | 0.31407863 | 0.04214988 | 0.109388 | 0.015431572 | 0.04495621 |
| \|DZ\| | 0.48153374 | 0.46805163 | 0.63229566 | 0.44624474 | 0.43772372 | 0.377275207 | 0.17471498 |
| *C3'*\|DX\| | 0.20556396 | 0.04460482 | 0.015633901 | 0.186190026 | 0.00067797 | 0.00143054 | 0.07189255 |
| \|DY\| | 0.20080151 | 0.112357885 | 0.29241791 | 0.0135474 | 0.08347998 | 0.015161544 | 0.06112237 |
| \|DZ\| | 0.4627569 | 0.46379527 | 0.62150797 | 0.46071871 | 0.40178999 | 0.392212794 | 0.19453121 |
| *C4'*\|DX\| | 0.205034051 | 0.02942467 | 0.073992265 | 0.10066588 | 0.087029769 | 0.023406383 | 0.0783313 |
| \|DY\| | 0.24023629 | 0.068061671 | 0.28421959 | 0.03056225 | 0.14459044 | 0.005863142 | 0.01729516 |
| \|DZ\| | 0.45531449 | 0.61471002 | 0.61809788 | 0.33730034 | 0.63221312 | 0.338477365 | 0.09772056 |
| *C5'*\|DX\| | 0.191206163 | 0.00068035 | 0.016382266 | 0.094778223 | 0.105010283 | 0.042320327 | 0.11843101 |
| \|DY\| | 0.23618448 | 0.05418348 | 0.3311152 | 0.027006293 | 0.20278447 | 0.00404698 | 0.02133356 |
| \|DZ\| | 0.49340275 | 0.54285772 | 0.70319796 | 0.25345589 | 0.68414723 | 0.292427076 | 0.09283983 |
| *C6'*\|DX\| | 0.138891345 | 0.12645952 | 0.069574209 | 0.152684929 | 0.10816532 | 0.03243222 | 0.031739255 |
| \|DY\| | 0.21065051 | 0.105985197 | 0.31666825 | 0.05106682 | 0.06296262 | 0.045549702 | 0.09008835 |
| \|DZ\| | 0.32469491 | 0.4106397 | 0.51163437 | 0.38437469 | 0.29368501 | 0.360918102 | 0.21071631 |
| *C7'*\|DX\| | 0.226465853 | 0.05073092 | 0.0295242 | 0.287233915 | 0.07579865 | 0.03212434 | 0.06783382 |
| \|DY\| | 0.17685873 | 0.136278914 | 0.31033831 | 0.008245655 | 0.05873559 | 0.019946916 | 0.09042322 |
| \|DZ\| | 0.40386797 | 0.39809555 | 0.60138931 | 0.39625834 | 0.3475388 | 0.364849033 | 0.21328775 |

| | | Mean | Std Deviation | p value | | | Mean | Std Deviation | p value |
|---|---|---|---|---|---|---|---|---|---|
| **L Asterion** | X | *64.84* | *0.03* | *≤.0001* | ***R Asterion*** | *X* | *68.74* | *0.08* | *0.82* |
| | Y | *51.52* | *0.03* | *≤.0001* | | *Y* | *47.07* | *0.06* | *≤.0001* |
| | Z | *8.83* | *0.07* | *≤.0001* | | *Z* | *14.5* | *0.15* | *≤.0001* |
| **L Pterion** | X | *55.08* | *0.05* | *0.01* | ***Bregma*** | *X* | *4* | *0.03* | *0.78* |
| | Y | *17.83* | *0.03* | *≤.0001* | | *Y* | *0.26* | *0.02* | *0.1* |
| | Z | *39.33* | *0.08* | *≤.0001* | | *Z* | *105.59* | *0.04* | *≤.0001* |
| **Naison** | X | *0.42* | *0.04* | *0.16* | ***Lambda*** | *X* | *7.26* | *0.05* | *0.01* |
| | Y | *76.44* | *0.03* | *≤.0001* | | *Y* | *102.7* | *0.23* | *0.36* |
| | Z | *5.52* | *0.06* | *≤.0001* | | *Z* | *57.72* | *0.05* | *≤.0001* |
| **R Pterion** | X | *61.48* | *0.06* | *≤.0001* | *Sensitivity p≤0.05* | | | | |
| | Y | *14.85* | *0.03* | *0.14* | | | | | |
| | Z | *22.14* | *0.07* | *≤.0001* | | | | | |

- Preponderance of the data shows that there is a significant difference of the models from the standard@ P≤0.05.
- Maximum deviations were within the size of a voxels dimensions, but the standard deviation between the models were minimal.

## Discussion

- Deviations from the standard are minimal in the X and Y axis, but more noticeable in the Z axis
- Z axis is the defining resolution on the SLA (build quantization error and overcure error)
- Z axis is the defining resolution on CT Scan (Axial Slice thickness)



*Distribution of a fiducial point within an orthotropic voxel*

## Conclusions

The results of this study indicate that in a controlled setting, the greatest discrepancies of medical model fabrication correspond to the largest dimension of the orthotropic voxel volume of the MDCT scan, which is related to the slice thickness of the scan and the Z axis of the RP model. Clinicians should be aware that the traditional imaging protocols for diagnosis that allow for large slice thickness, although they provide less exposure to the patient, may be less desirable for use in surgical manipulation software and accurate rapid prototype models and implants.