Comparison of Cone Beam CT to Conventional CT in Accuracy of Rapid Prototype Models: Image Registration

Shayne Kondor, MSAE, Gerald T. Grant, DMD, MS, Robert M. Taft, DDS
Naval Postgraduate Dental School, National Naval Medical Center, Bethesda, MD
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Objective

Validate the use of Cone Beam CT (CBCT) generated models for treatment planning and rapid prototyping by comparison to an standard derived from a conventional CT scan.

Background

Warfighter casualties often involve serious trauma to the head and neck. Reconstruction of these injuries, based only on post-trauma medical CT scans, is based on estimation and often necessitates multiple operating room visits. If an accurate three dimensional pre-trauma model of the warfighters' head and neck were available from pre-deployment records, a precise reconstruction could be planned, along with custom surgical guides and implants. This would result in a more predictable outcome, of greater aesthetic quality, achieved in less time and fewer operative procedures. However, the cost and radiation exposure of a conventional CT scan make it infeasible to consider for a such a record. CBCT scanners have been developed which deliver volumetric models at a fraction of the radiation exposure and cost of conventional CT. A comparison of the accuracy of a CBCT to conventional CT is necessary to assess the viability of this new technology as a means to obtain a pre-deployment record of craniofacial structure.

Materials and Methods

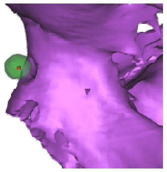
Three dimensional digital model of a conventional CT scan of a phantom was obtained as a benchmark for comparison. CBCT scans were obtained from three different devices, two with solid state flat panel detectors, and one with an intensifier tube configuration. Digital models generated from the CBCT scans were mathematically registered to the conventional CT model by alignment of extrinsic fiducial markers. Once aligned, deviations from the conventional CT were computed in Euclidean space. Deviations among the models were compared by Multivariate Analysis of Variation (MANOVA).

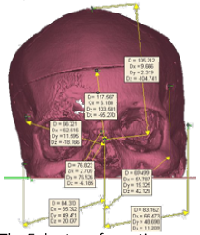
Sample Group	Scanner Model	Exposure		Voxel Resolution (mm)		Detector Type
		kV	mAs	Planar Resolution (X-Y Plane)	Slice Spacing (Z axis)	
1	Imtec Iluma	120	23	0.389	0.389	Amorphous Silicon Flat Panel CCD
2	Imtec Iluma	120	60	0.389	0.389	Amorphous Silicon Flat Panel CCD
3	Imtec Iluma	120	120	0.389	0.389	Amorphous Silicon Flat Panel CCD
4	Newtom 3G	110	10	0.400	0.420	CCD w/Intensifier Tube
5	Kodak K9500	85	129.6	0.300	0.300	Amorphous Silicon Flat Panel CCD
Control	Philips Brilliance 40	120	400.5	0.488	0.625	X-ray Tube Anode

Materials and Methods (cont.)

An imaging phantom was produced from a dry cadaver skull, fitted with stainless steel spheres (5mm dia.) as extrinsic fiducial markers. Seven spheres were placed on the skull at exterior anthropomorphic landmarks, and one at the Selle in the central cranial fossae; these markers facilitated objective, observer independent comparison of scans. For each scan the skull was positioned so that reconstructed axial slice images were arrayed from the base of the skull up to the vertex of the calvarium. Tomographic data sets (discrete slices) were computed using the respective devices' workstation and software.

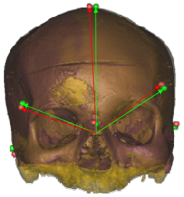
Three dimensional digital models, in STL format, were generated from the DICOM tomographic data set of each scan using MIMICS modeling software (Materialise N.V., Lueven, Belgium). Spherical fiducial markers were segmented from the scan and eroded down to only the centroid voxel using discrete morphology tools in MIMICS. Positions of the seven external fiducial marker centroid voxels were measured in reference to the centroid of the Selle using Magics RP software application (Materialise, N.V., Leuven, Belgium).





Measurements were resolved in a Cartesian coordinate system with the origin at the centroid of the Selle marker, and the XZ Plane approximating the mid-sagittal plane of the skull. Positions of each surface marker were resolved along each axis. Using a common origin point for each scan, only an rotation was necessary to mathematically register the CBCT and CT models. An Euler transformation matrix was computed between each CBCT and the conventional CT model using a least squares approach.

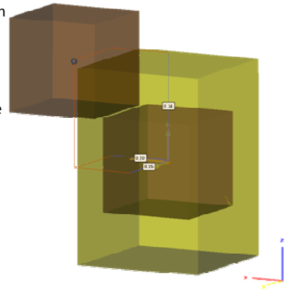
The Euler transformation was computed and applied to each CBCT measurement set in Microsoft Excel, providing a best alignment of the models. Absolute deviations between each surface fiducial marker centroid were computed in the transformed coordinates: $|\Delta X|$, $|\Delta Y|$, $|\Delta Z|$.
Deviations were analyzed by MANOVA using IBM SPSS Statistics 19 (IBM, Chicago, IL).



Results and Discussion

Deviations between the CBCT and conventional CT scan models were compared across the entire sample set using MANOVA. Computed marginal means showed that the mean registration error on any axis fell within the smallest voxel dimension of the five CBCT groups. Furthermore, the upper bounds of the 95% confidence interval fell within the voxel dimension of the conventional CT, along the respective axes.

The maximum registration error can be shown graphically by superimposing CBCT voxel (brown) on the conventional CT voxel (gold). When translated to the extents of the 95% confidence interval, the CBCT voxel always partially overlaps the conventional CT voxel. Thus, both scans register within the discrete uncertainty of the tomographic data set.



Component	Mean (mm)	Standard Error (mm)	95% Confidence Interval (mm)	
			Lower Bound	Upper Bound
$\lvert\Delta X\rvert$	0.151	0.022	0.107	0.196
$\lvert\Delta Y\rvert$	0.209	0.027	0.154	0.263
$\lvert\Delta Z\rvert$	0.273	0.035	0.202	0.343

Differences among the CBCT groups were investigated by testing the null hypothesis:
$H_0 : \mu_1 = \mu_2 \dots \mu_n$, with significance of $p < 0.05$ necessary for rejection

Using the Hotel ling's T^2 multivariate test the observed level of significance was: $p = 0.283$, suggesting that the vector means of the groups were not significantly different.
Thus, any one of the digital models generated from CBCT data will register to the conventional CT within a similar range of error: approximately one voxel dimension along any axis.
Furthermore, the x-ray exposure, type of x-ray detector, and voxel resolution did not result in detectable differences in the mean deviations.

Conclusions

Based on registration of fiducial markers, it appears that three dimensional digital models based on CBCT scan will register to models from conventional CT, within a single voxel (the discrete uncertainty inherent to the scans). Furthermore, the effects of CBCT exposure, detector type, and resolution do not cause significant differences in the quality of model registration.

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