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Automated Measurement of Skull Circumference, Cranial Index, and Braincase Volume from Pediatric Computed Tomography

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STUDY RATIONALE

Normative Pediatric Skull Metrics

- Beneficial for multiple disciplines
  - Plastic Surgery
    - Normal vs deformed, surgical planning
  - Neurology
    - Epilepsy presurgical evaluations
  - Anthropology
    - Human evolution, models of skeletal change
  - Electrical/Optical source imaging models
- Aided by development of automated measurement techniques

POTENTIAL DATA SOURCES

Clinical Magnetic Resonance Imaging (MRI)

- Commonly acquired for head trauma and/or pathology
- Often requires sedation in young children
- Does not provide good definition of bone

Clinical Computer Tomography (CT)

- Provides high fidelity representations of craniofacial bone
- Preferred modality for imaging bone
- Ionizing radiation is used; concerns raised in children
- Head CT is acquired in head trauma cases to rule out fracture/ hematoma
- Negative CT results with clinical signs justifies MRI
- Clinically acquired CT often read as ‘normal’

STUDY DESIGN

- Subset of a large retrospective study population (n=21)
- CT scans all radiologically normal
- Evaluations of skull morphology based on
  - Braincase volume
  - Skull circumference
  - Cranial/Cephalic index
- Current methods depend on interactive analyses which are time consuming
- Focus on development of automated extractions
- Compare automated results to those obtained with semi-automated methods

STUDY METHODS: DATA COLLECTION

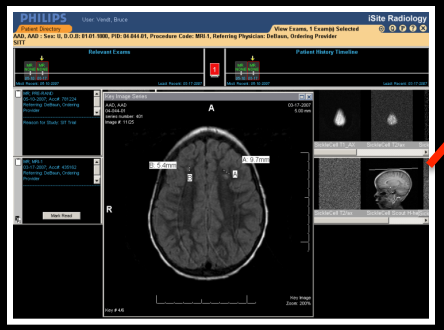
Inclusion Criteria

Age range birth to 18 years

Exclusion Criteria

Pathology, deformity, surgery

RisSearch Query



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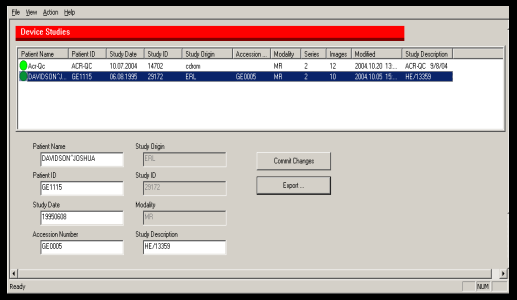
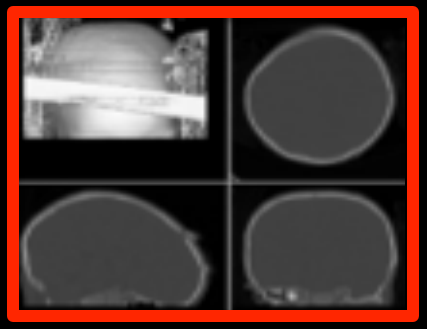
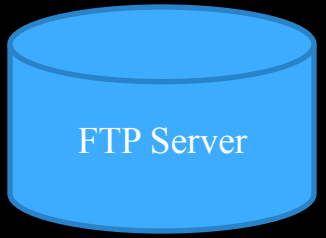
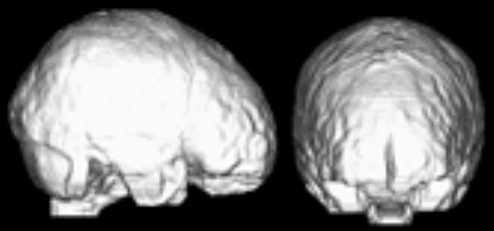
Anonymization







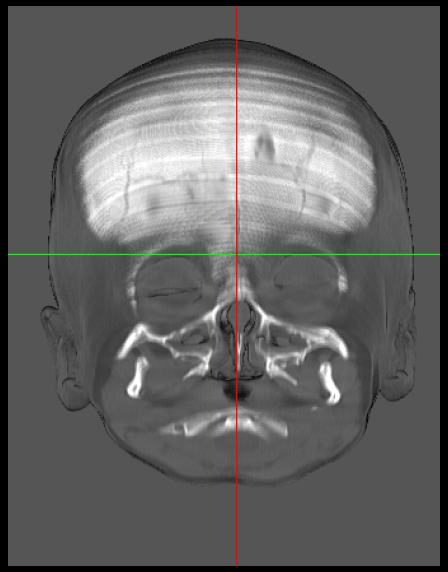


Segmentation

Co-registration

STUDY METHODS: PREPROCESSING

- Convert DICOM data to Analyze 7.5 format
- Resample CT Data (0.5 mm^3 voxels)
- Define Landmarks on CT data



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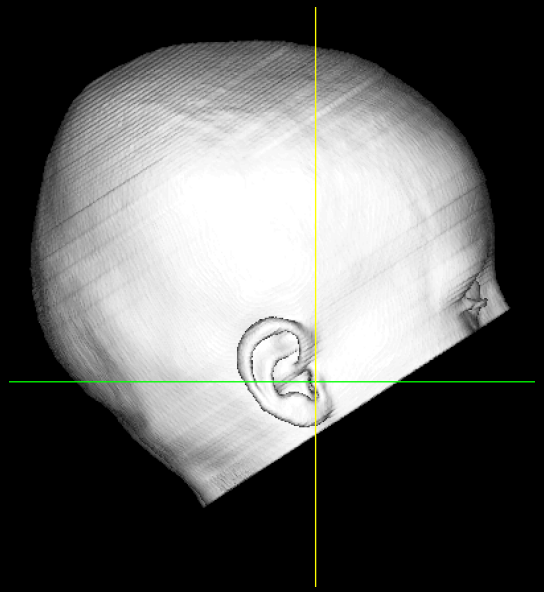
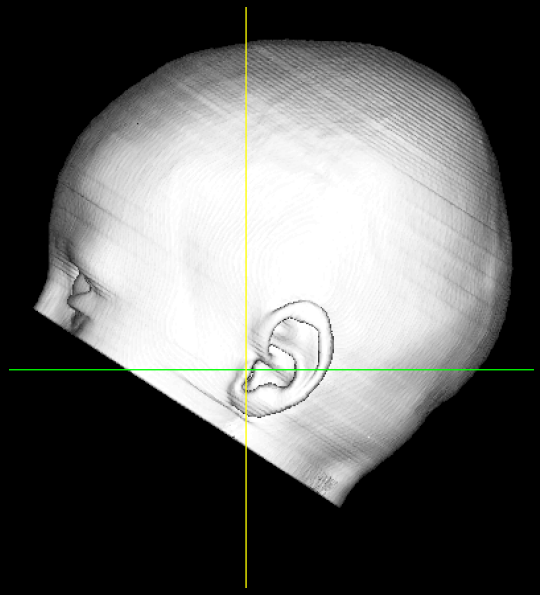


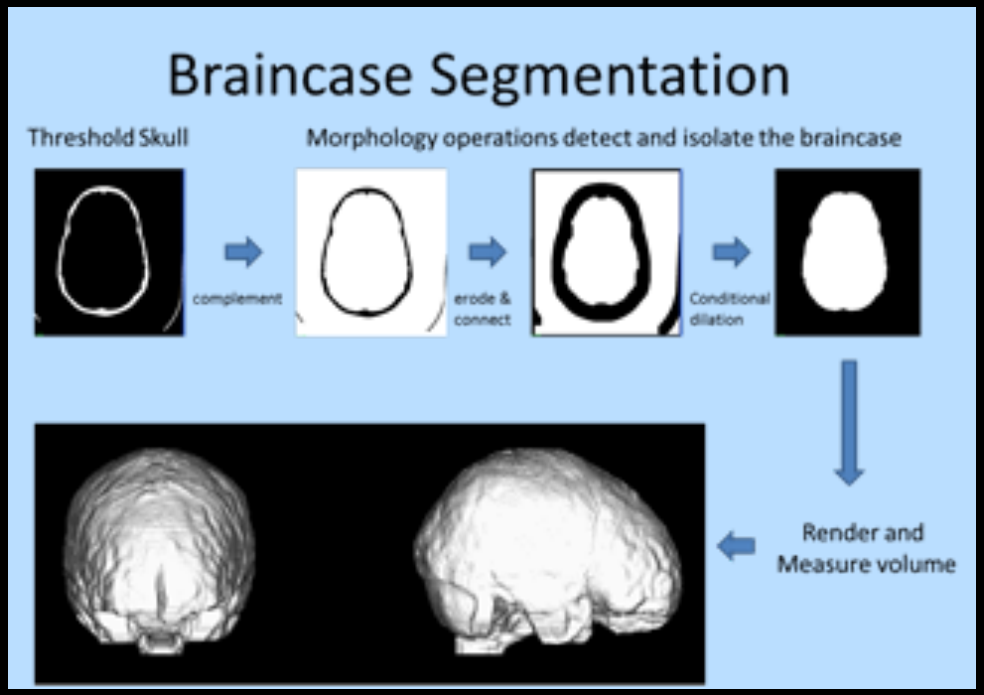
Pre Auricular Right

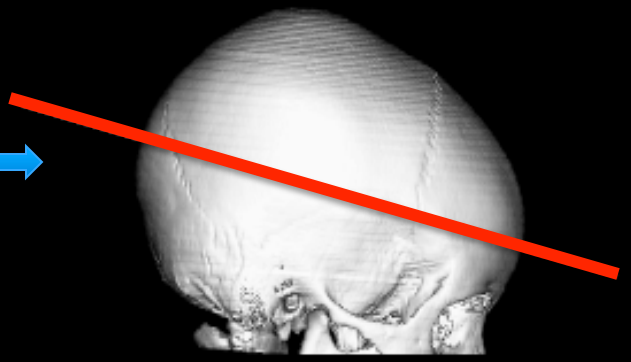


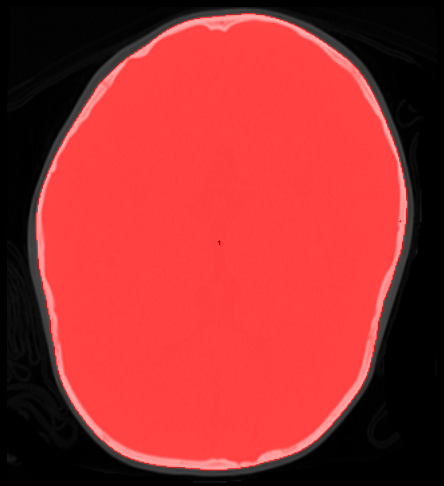
Pre Auricular Left

- Transform to common axial plane (automated rigid body transformation

STUDY METHODS: PROCESSING

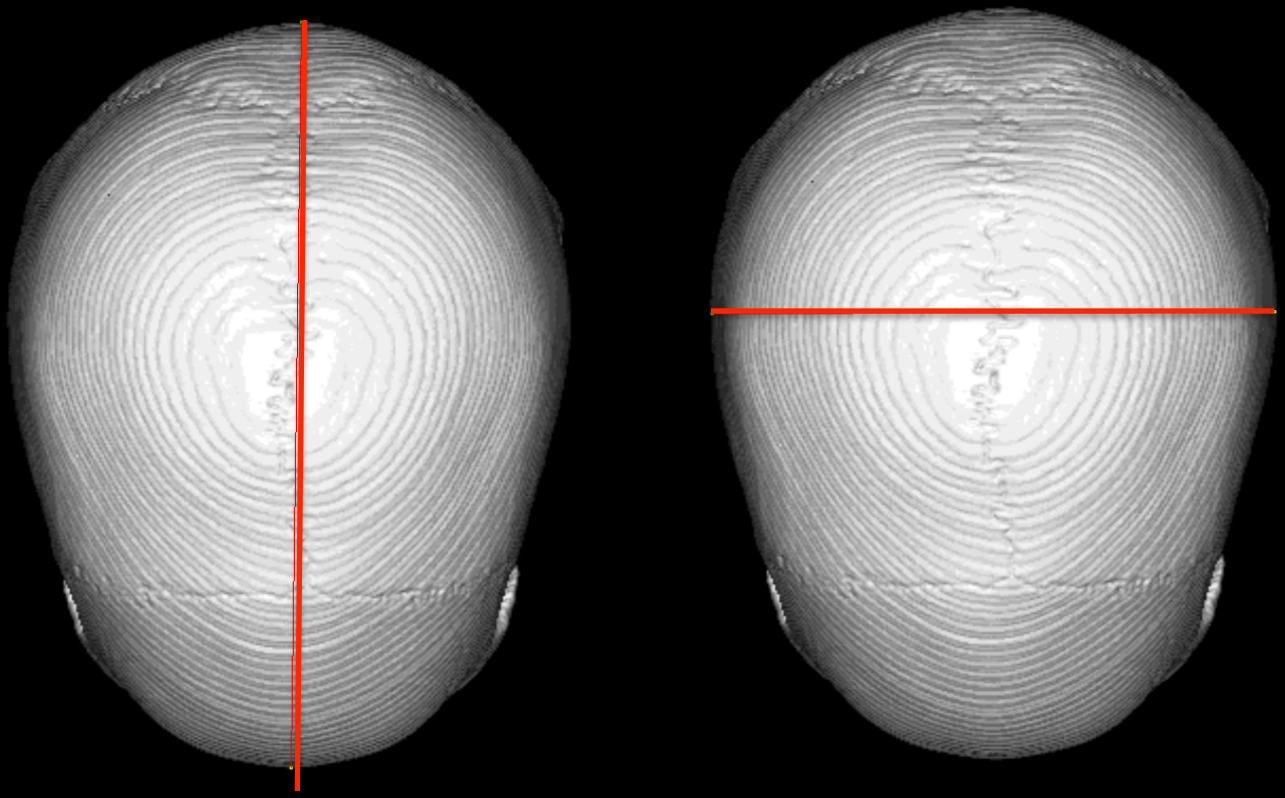






- Global threshold for skull/scalp boundary
- 3D rendering of extracted skull
- Head aligned to common coordinate system
- Cutting plane intersects frontal and occipital poles
- Circumference measured in cutting plane

STUDY METHODS: PROCESSING



Cranial Index = Skull width/length * 100%

Automated fit for max x, y, z dimensions

STUDY RESULTS

Data were analyzed using two methods:

- Semi-automated (gold standard)
  - ANALYZE
- Automated (test)
  - MATLAB

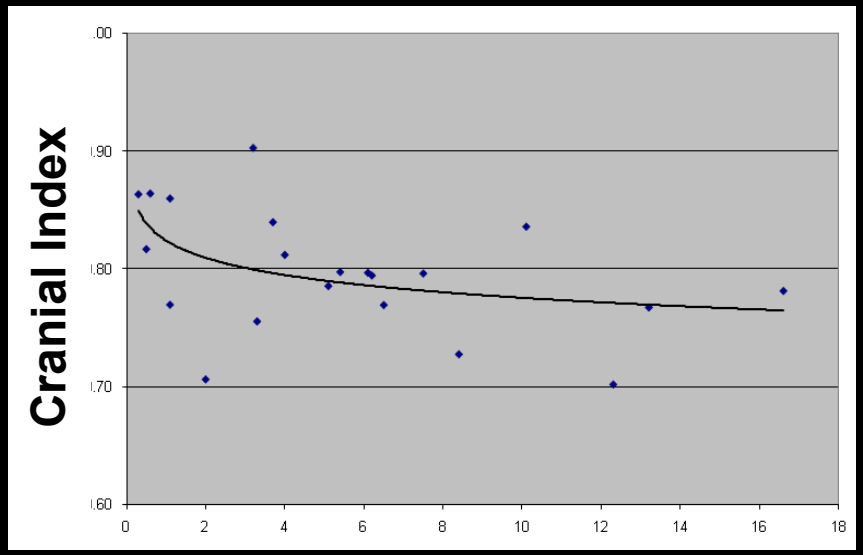
Measures of interest:

- Cranial index
- Braincase volume
- Skull circumference

Statistical Analysis:

- Shapiro-Wilk W test for normality
- Wilcoxon signed-rank test for non-normally distributed
- Display using Bland-Altman plot of mean difference and 95% limits of agreement

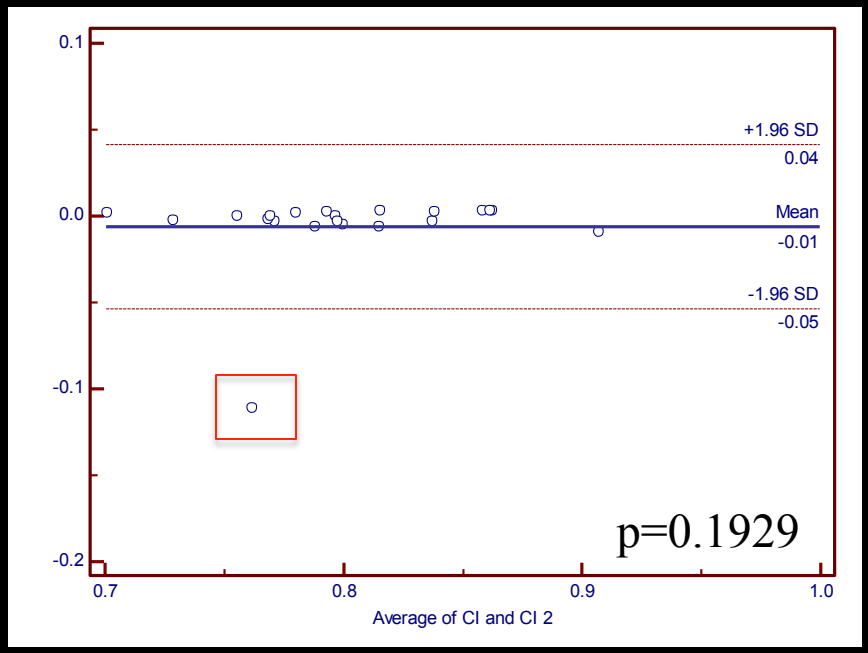
RESULTS: CRANIAL INDEX



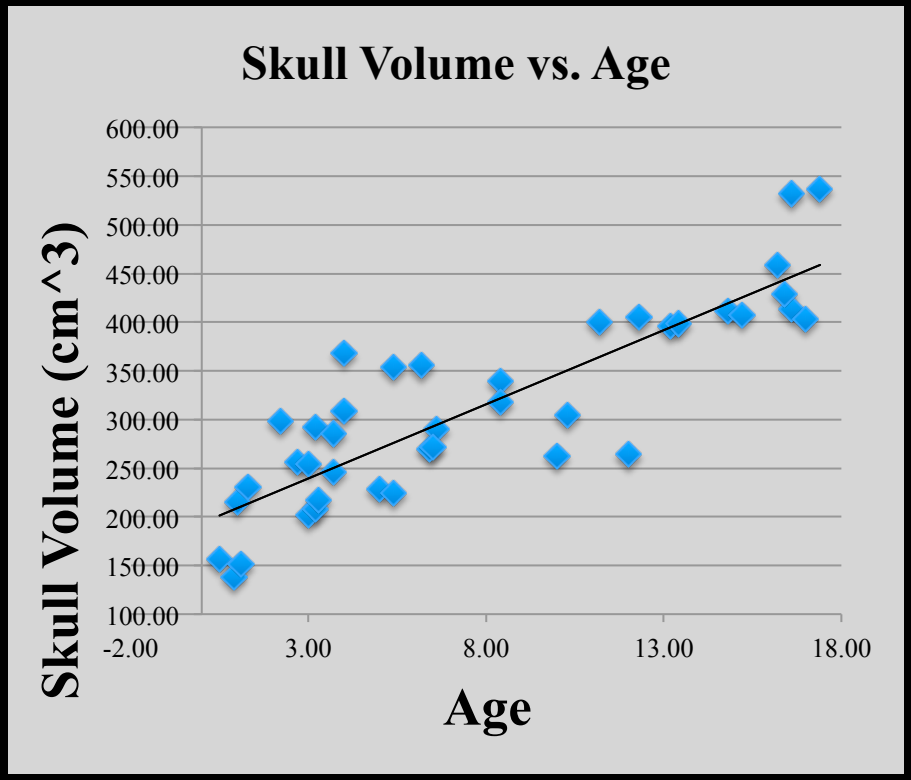
Cranial Index Scales with age

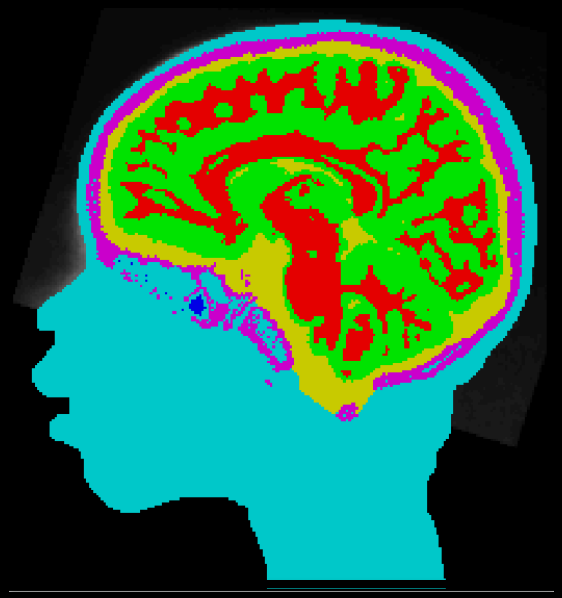
Both length and width increase with head shape becoming more oval

- No significant difference between methods
- One outlier –transcription error in semi-automated method.



RESULTS: BRAIN VOLUME

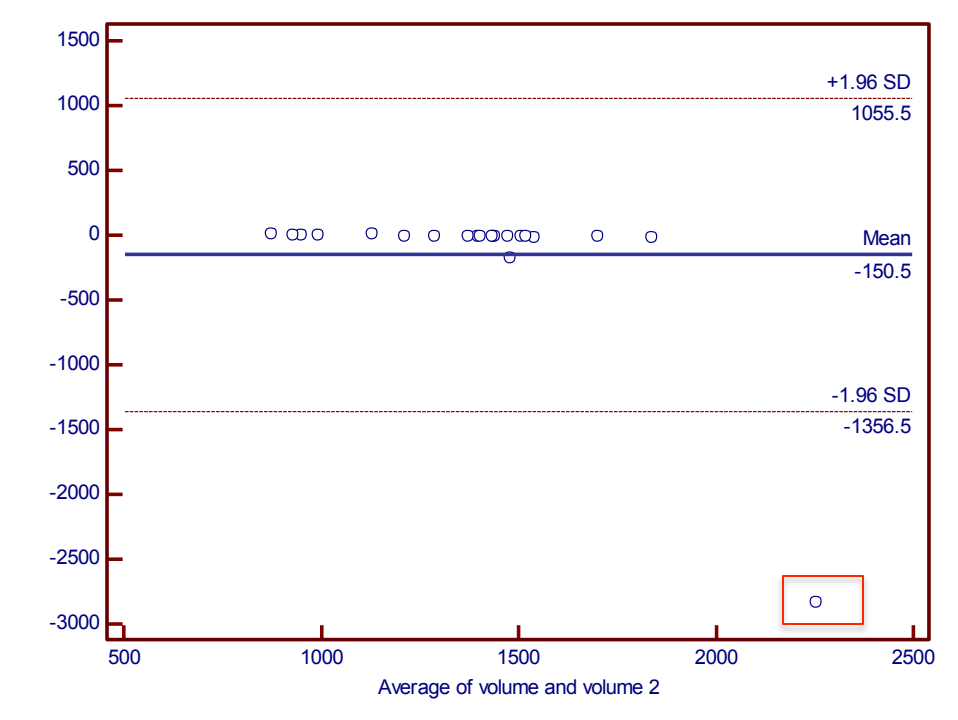




Volume scales linearly with age

- n=41 ages 0.5-18
- MRI segmentation (BrainK, EGI)

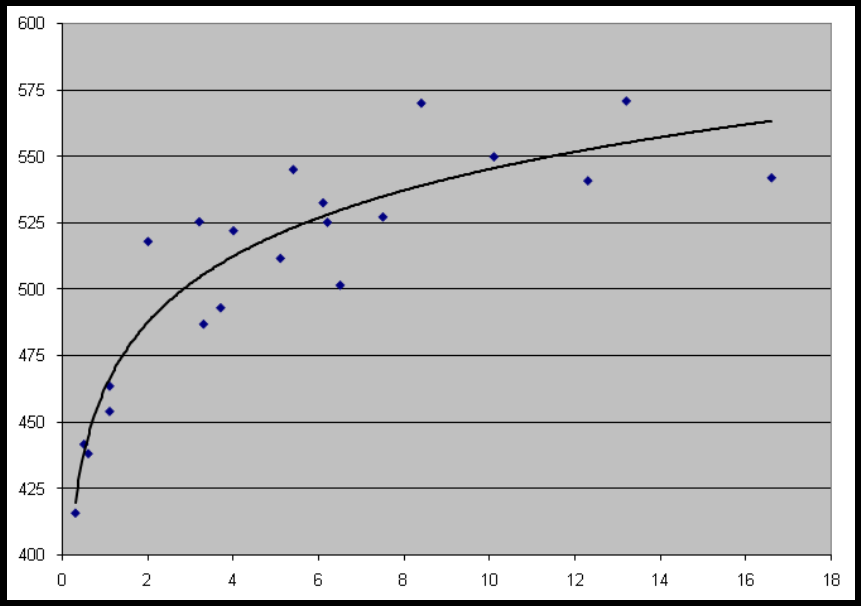
RESULTS: BRAINCASE VOLUME



- Wilcoxon signed rank test (data non normally distributed)
- Measures were significantly different p = 0.0001
- Outlier, PV3015 failed automated BC segmentation
- Bias of -150 cm^3 for automated drops to -10 cm^3 PV3015 removed

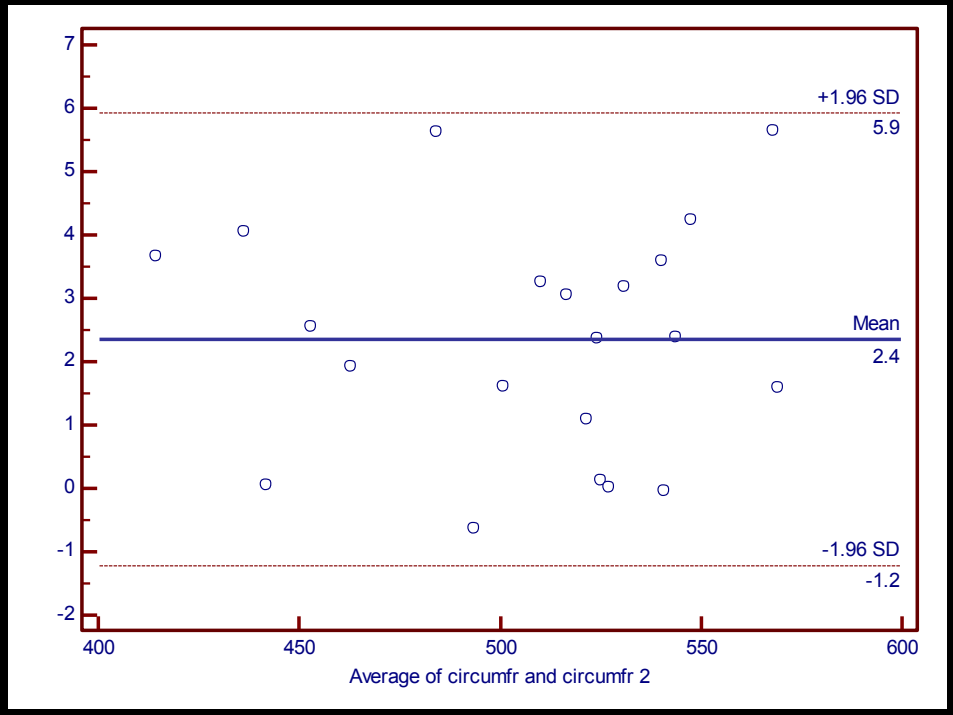
Semi-automated	Automated (brain_calc)	Differences
1428.9	1442.3	-13.4
946.1	950.6	-4.5
1391.6	1401.8	-10.2
1826	1846.8	-20.8
1433	1445.2	-12.2
1468.9	1478.7	-9.8
1393	1564.3	-171.3
1500	1513.2	-13.2
1693.3	1705.3	-12
1530	1550.1	-20.1
877.4	872.7	4.7
991.8	991.2	0.6
928	930	-2
839.5	3670.8	-2831.3
1284	1292	-8
1513.3	1524.1	-10.8
1133.5	1127.8	5.7
1430.3	1436.6	-6.3
1369.8	1374.4	-4.6
1208.6	1215.4	-6.8
1395.6	1409.2	-13.6

RESULTS: SKULL CIRCUMFERENCE



Skull Circumference Scales with age

- Paired t-test
- Significant difference (p = 0.0001)
- Differences not clinically meaningful (max 5.6 mm)
- Bias of 2.4 mm with automated measures slightly smaller



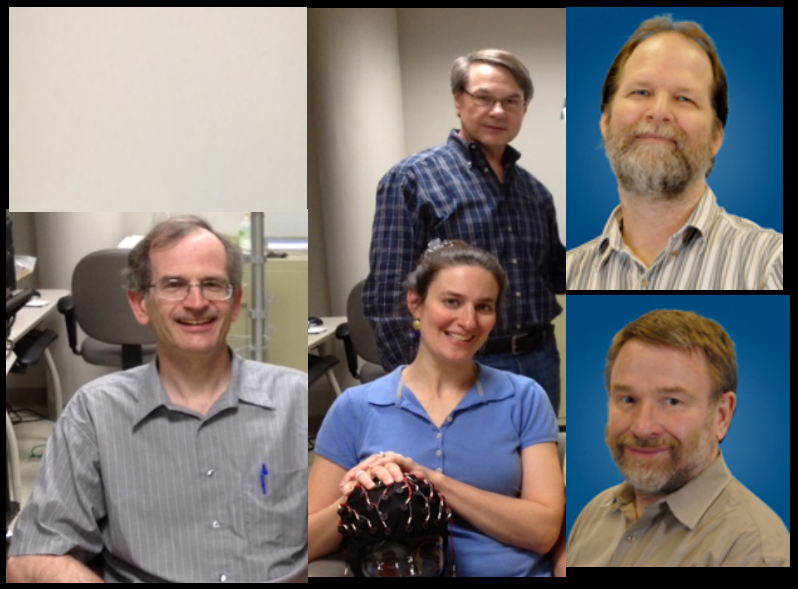
CONCLUSION

- Automated MATLAB based metrics are in good agreement with semi-automated ANALYZE based metrics
- Automated procedures can fail for certain cases, so image review and range checks should be performed
- Automated metrics in MATLAB do not require a trained operator, eliminates potential transcription errors, and saves valuable man hours
- Open source automated methods will contribute difficult to obtain measures of normal pediatric skull morphology and add them to the paucity of existing data
- https://mirgforge.wustl.edu/gf/project/normalcy/

ACKNOWLEDGEMENTS

Study team:

Washington University in St. Louis
School of Medicine



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Reducing the burden of neurological disease...