CranioRate™:

Leveraging advanced Machine Learning to Create a Point-of-care Operative Decision Aid for Craniosynostosis

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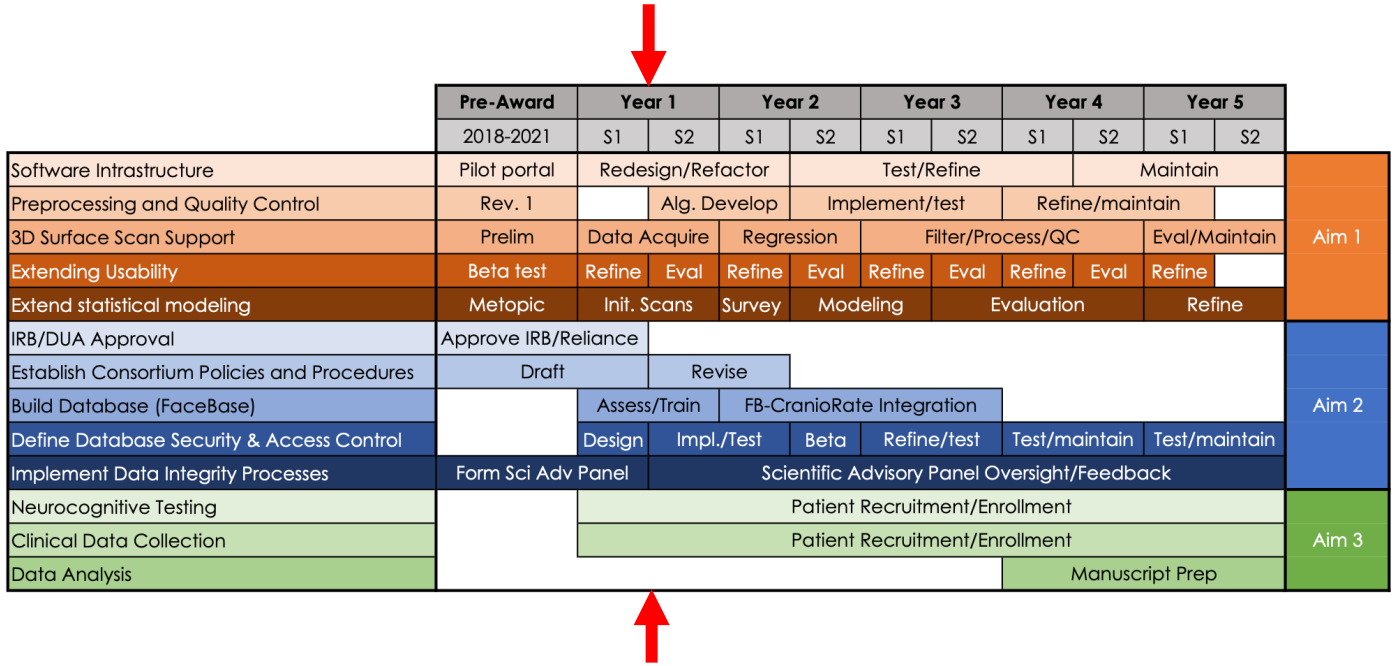
Children's Hospital of Pittsburgh
University of Pittsburgh Medical Center

Children's Hospital of Pittsburgh of UPMC

Disclosures

- This project was previously supported by a PSF National Endowment Grant [2022-2023]
- This project is currently funded by the NIH/NIDCR (R01-DE032366-01) [2023-2028]
- We are early in our funding term



	Pre-Award	Year 1		Year 2		Year 3		Year 4		Year 5		
	2018-2021	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	
Software Intrastructure	Pilot portal	Redesign/Refactor			Test/Refine				Maintain			
Preprocessing and Quality Control	Rev. 1		Alg. Develop		Implement/test			Refine/maintain				
3D Surface Scan Support	Prelim	Data Acquire		Regression		Filter/Process/QC				Eval/Maintain		Aim 1
Extending Usability	Beta test	Refine	Eval	Refine	Eval	Refine	Eval	Refine	Eval	Refine		
Extend statistical modeling	Metopic	Init. Scans		Survey	Modeling		Evaluation			Refine		
IRB/DUA Approval	Approve IRB/Reliance											
Establish Consortium Policies and Procedures	Draft		Revise									
Build Database (FaceBase)		Assess/Train		FB-CranioRate Integration								Aim 2
Define Database Security & Access Control		Design	Impl./Test		Beta	Refine/test		Test/maintain		Test/maintain		
Implement Data Integrity Processes	Form Sci Adv Panel	Scientific Advisory Panel Oversight/Feedback										
Neurocognitive Testing		Patient Recruitment/Enrollment										Aim 3
Clinical Data Collection		Patient Recruitment/Enrollment										
Data Analysis								Manuscript Prep				

Overview

- Project Overview
- Summary of Results
- Funding Objectives
- Data Sharing
- Human Subjects Protection
- IRB Schema

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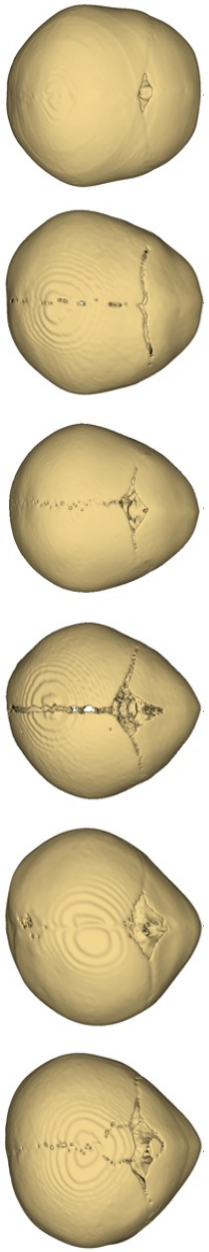
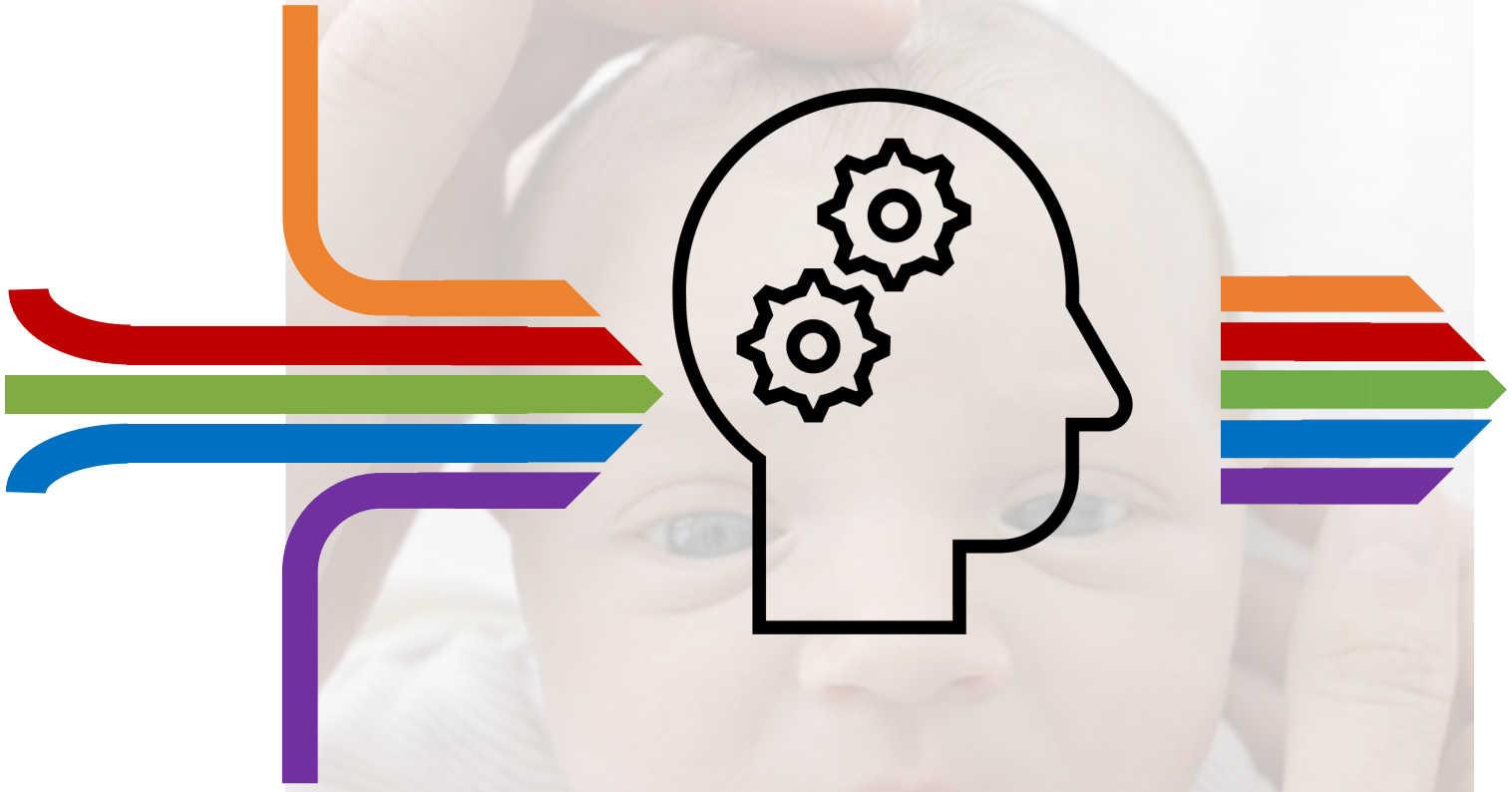


Education/Training



Clinical Experience

Diagnosis and Treatment Recommendations

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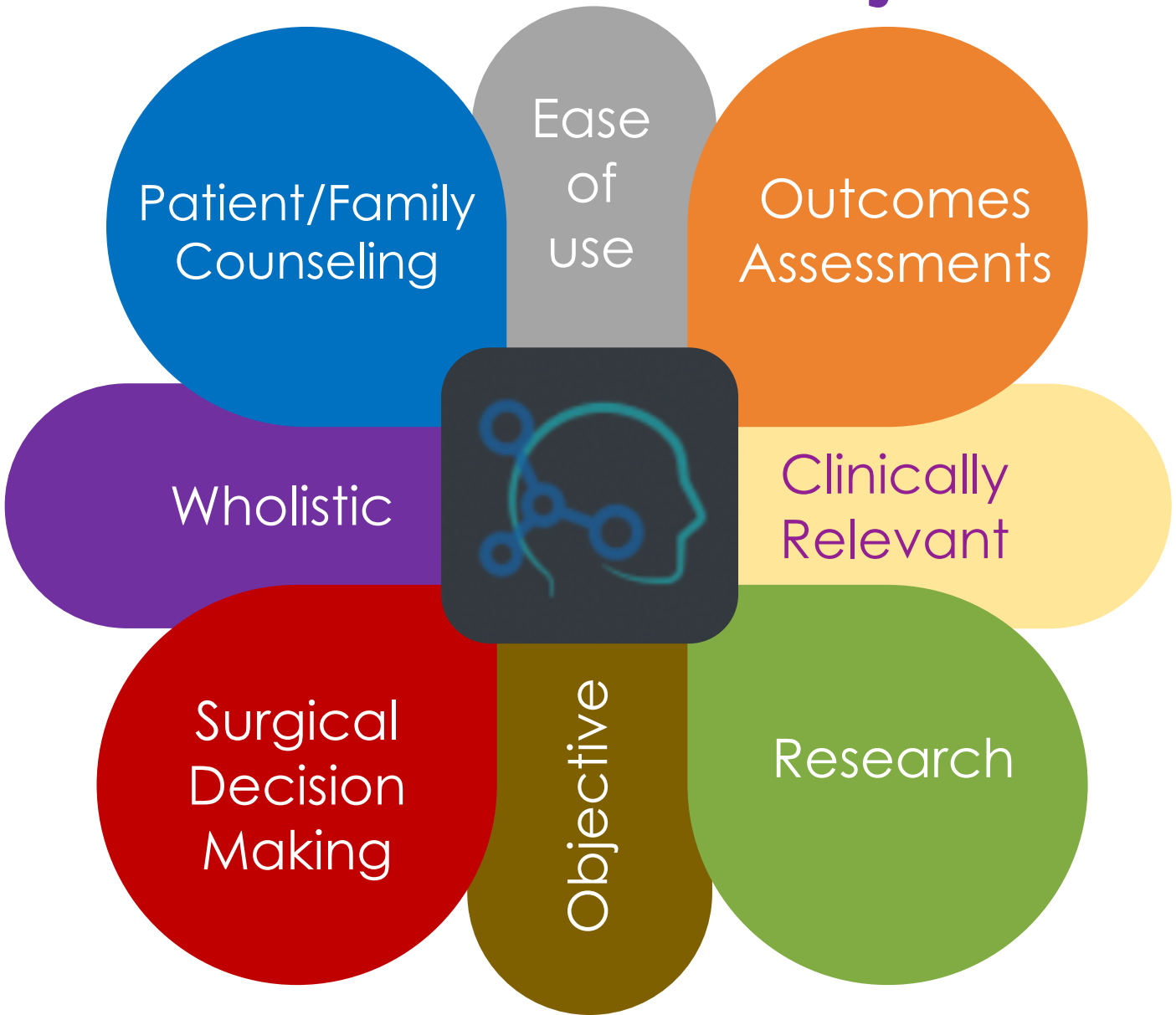
CranioRate™ Objectives



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Backbone algorithm behind CranioRate™

50 samples

36 experts

Evaluate

★★☆

1200 ratings

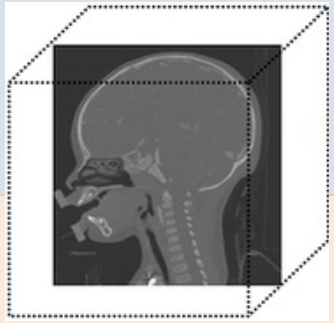
Linear regression

$$\begin{pmatrix} -0.9319 \\ -0.5529 \\ 0.7305 \\ 0.0594 \\ -0.5083 \\ -0.5604 \\ 0.9612 \\ 0.7647 \end{pmatrix}$$

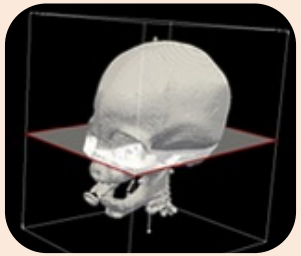
Shape descriptor

PCA

Segmentation



122 Images

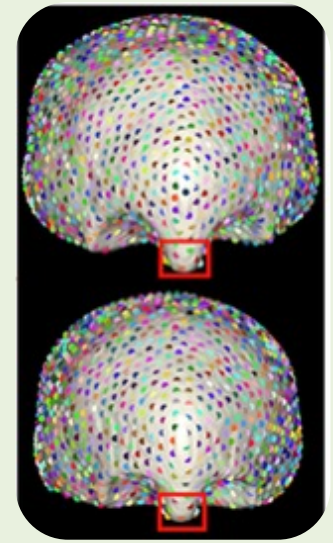


Anatomical plane

Crop

Region of interest

Shapeworks



Statistical shape modeling

CranioRate™ Outputs

CranioRate™

MSS Metopic Severity Score

Quantifying the Severity of Metopic Craniosynostosis: A Pilot Study Application of Machine Learning in Craniofacial Surgery

Riddhish Bhalodia, BS,[1] Lucas A. Dvoracek, MD,[2] Ali M. Ayyash, MD,[2] Ladislav Kavan, PhD,[1] Ross Whitaker, PhD,[1] and Jesse. A Goldstein, MD[2]

The Journal of Craniofacial Surgery. 2020;31(3):697.

CMD Cranial Morphology Deviation

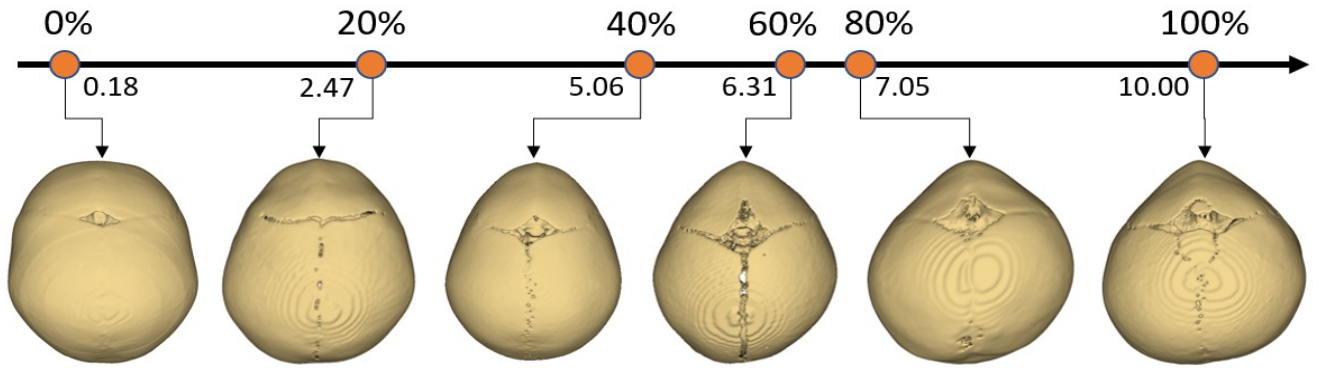
PEDIATRIC/CRANIOFACIAL: ORIGINAL ARTICLES

Quantifying the Severity of Metopic Craniosynostosis Using Unsupervised Machine Learning

Anstadt, Erin E. MD[1]; Tao, Wenzheng[2]; Guo, Ejay[2]; Dvoracek, Lucas MD[1]; Bruce, Madeleine K. BA[3]; Grosse, Philip J.[4]; Wang, Li[4]; Kavan, Ladislav PhD[2]; Whitaker, Ross PhD[2]; Goldstein, Jesse A. MD[3]

Author Information

Plastic and Reconstructive Surgery 151(2):p 396-403, February 2023. | *DOI:* 10.1097/PRS.0000000000009853



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ROC analysis demonstrated a high diagnostic value of MSS

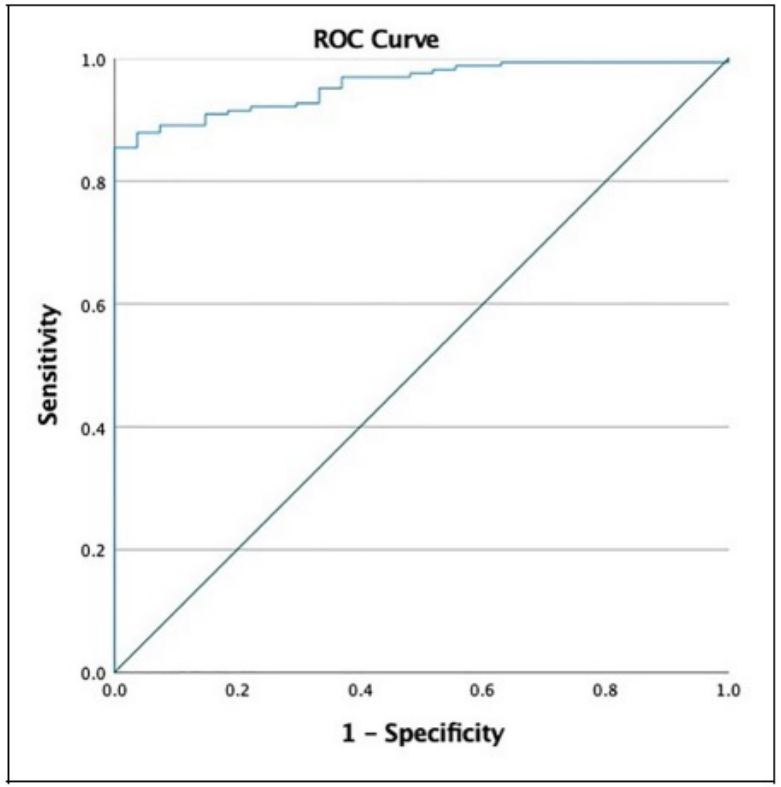

Figure 3. Receiver operating characteristic curve displaying the diagnostic value of the machine learning algorithm generated metopic severity score for distinguishing metopic craniosynostosis from controls.

MSS was equally correlated with phenotypic severity as traditional craniometric measurements

Original Article

ACPA American Cleft Palate Craniofacial Association

"Validation of Artificial Intelligence Severity Assessment in Metopic Craniosynostosis"

The Cleft Palate Craniofacial Journal 2021, Vol. 60(3) 274-279

DOI: 10.1177/1055665621106121
journals.sagepub.com/home/cpc
SAGE

Alexandra Junn, AB[1], Jacob Dinis, BS[1], Sacha C. Hauc, BS, MPH[1], Madeleine K. Bruce, BA[2], Kitae E. Park, MD[3], Wenzheng Tao[4], Cameron Christensen, MS[4], Ross Whitaker, PhD[4], Jesse A. Goldstein, MD[2], and Michael Alperovich, MD, MSc[1]

(Junn et al, CPCJ, 2021)

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Normal, Metopic, Sagittal and Post operative MSS and CMD

Normal control patients had lower MSS and CMD scores

Sagittal patients have high CMD scores, but normal MSS

PEDIATRIC/CRANIOFACIAL

CranioRate: An Image-Based, Deep-Phenotyping Analysis Toolset and Online Clinician Interface for Metopic Craniosynostosis

Justin W. Beiriger, BSE[1]
Wenzheng Tao, MS[1]
Madeleine K. Bruce, BA[1]
Erin Anstadt, MD[1]
Cameron Christensen, BS[1]
John Smetona, MD[1]
Ross Whitaker, PhD[2]
Jesse A. Goldstein, MD[1]
Pittsburgh, PA; and Salt Lake City, UT

Background: The diagnosis and management of metopic craniosynostosis involve subjective decision-making at the point of care. The purpose of this work was to describe a quantitative severity metric and point-of-care user interface to aid clinicians in the management of metopic craniosynostosis and to provide a platform for future research through deep phenotyping.
Methods: Two machine-learning algorithms were developed that quantify the severity of craniosynostosis—a supervised model specific to metopic craniosynostosis [Metopic Severity Score (MSS)] and an unsupervised model used for cranial morphology in general [Cranial Morphology Deviation (CMD)]. Computed tomographic (CT) images from multiple institutions were compiled

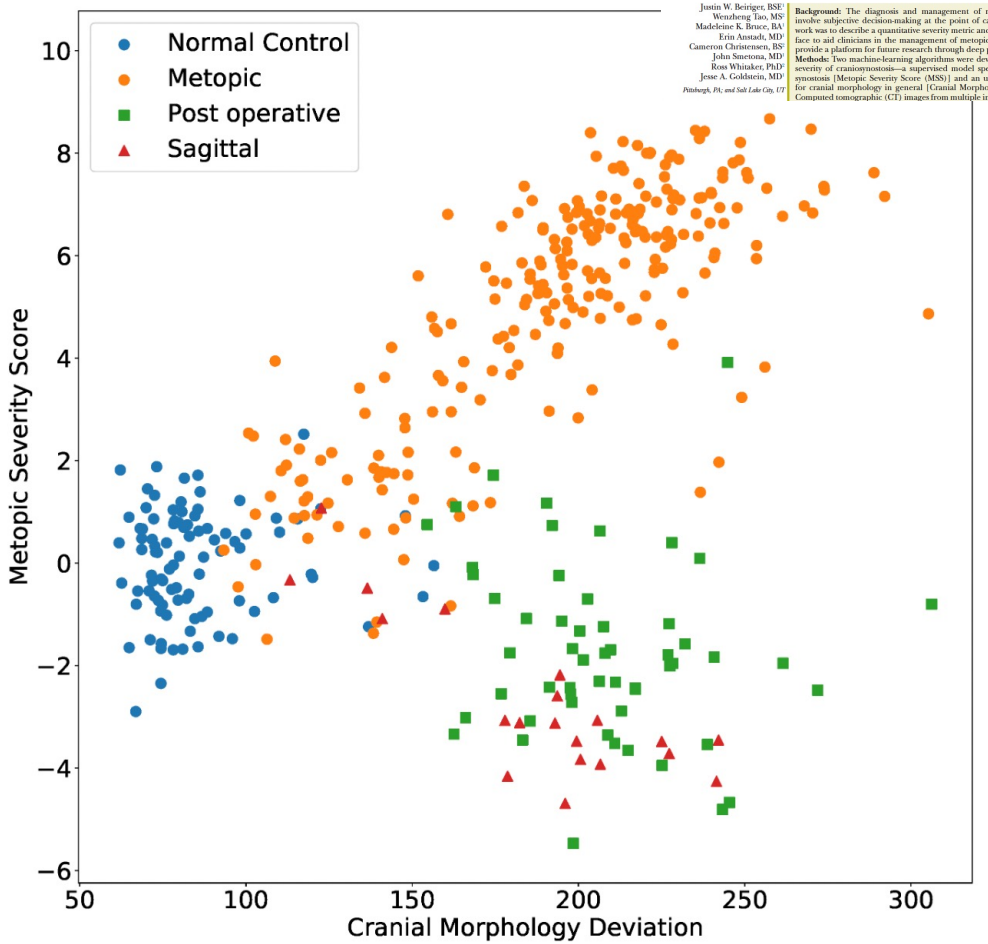

Figure - A scatter plot depicting the relationship between Metopic Severity Score and Cranial Morphology Deviation in three groups of patients: normal controls, metopic craniosynostosis, and postoperative scans following fronto-orbital advancement in patients with metopic craniosynostosis.

Metopic patients have the highest MSS

MSS scores became anti-metopic, while CMD remained elevated

(Berieger et al, PRS, 2024)

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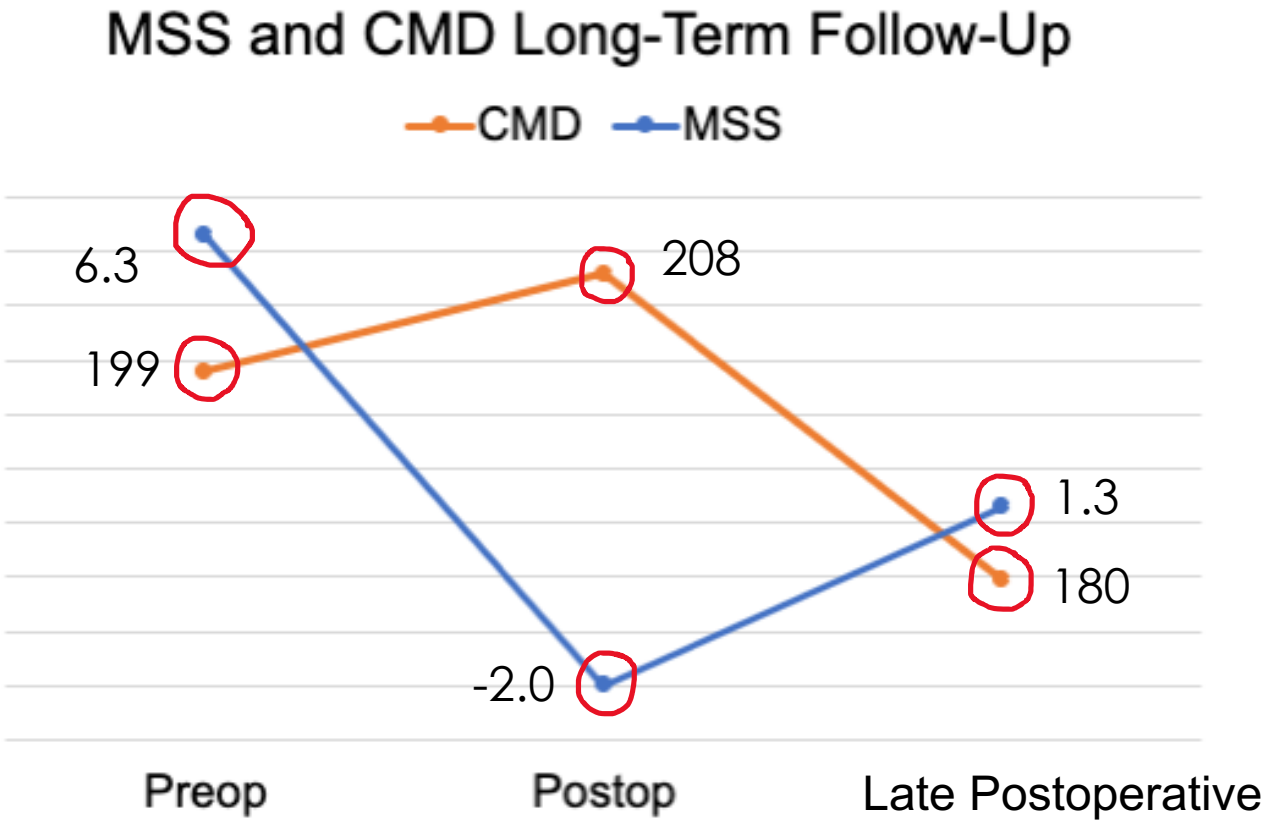
Post-op skulls move from “Anti-metopic” to normal over time.

55 Metopic patients

16 patients
- pre-op
- immediate post-op
- late post-op imaging



A Longitudinal Analysis of Pre- and Post-Operative Dysmorphology in Metopic Craniosynostosis

Journal:	*The Cleft Palate Craniofacial Journal*
Manuscript ID	CPCJ-23-0435.R1
Manuscript Type:	Original Article
Keywords:	Craniosynostosis, Outcomes, Artificial Intelligence

(Berieger et al, CPCJ, in press)

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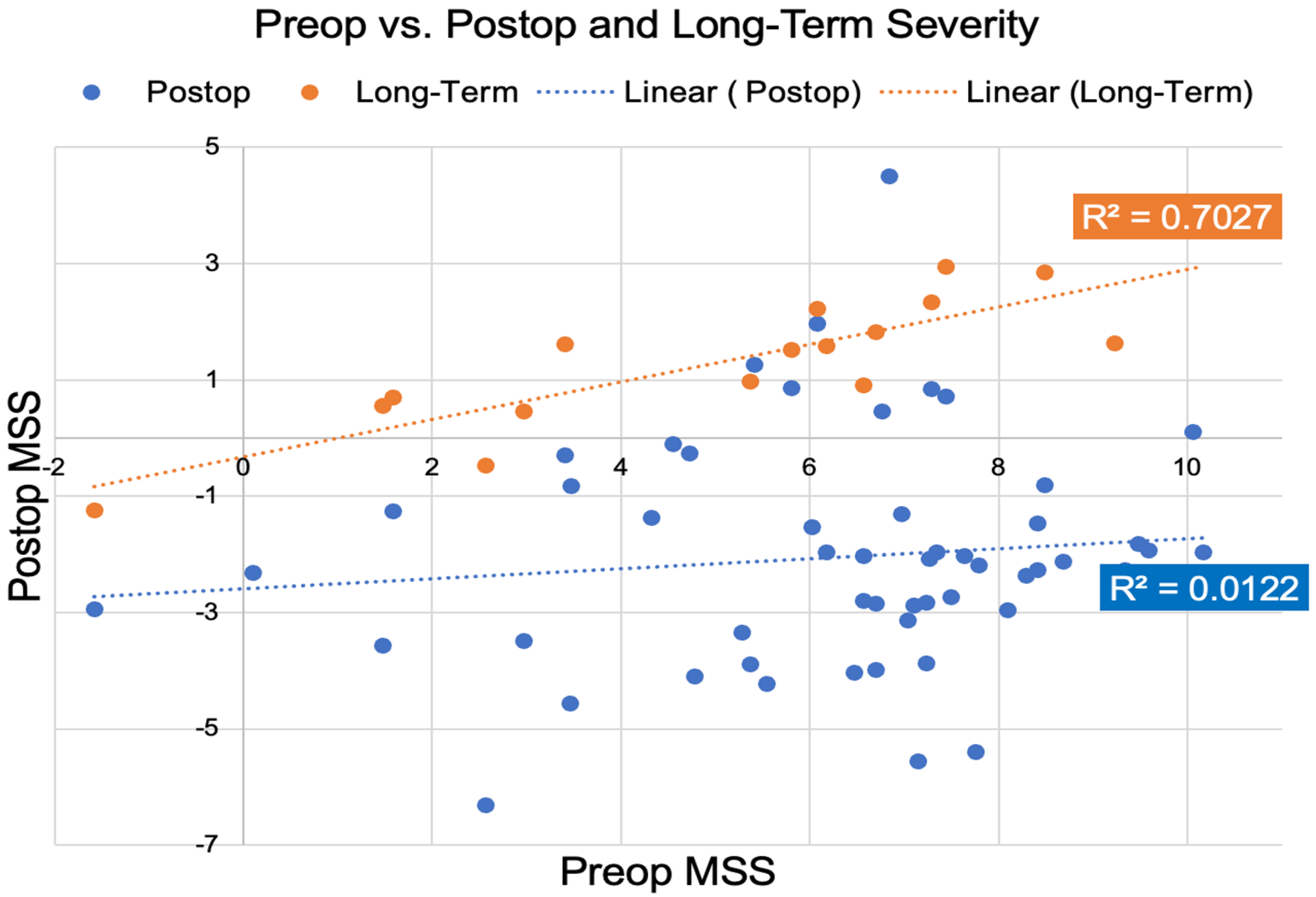
Pre-op severity is independent of immediate post-op severity and associated with late post-op severity.



Immediate Post-op

No correlation between pre-op severity and immediate post-op

Late Post-op

Preoperative severity correlates with late postoperative morphology

(Berieger et al, CPCJ, in press)

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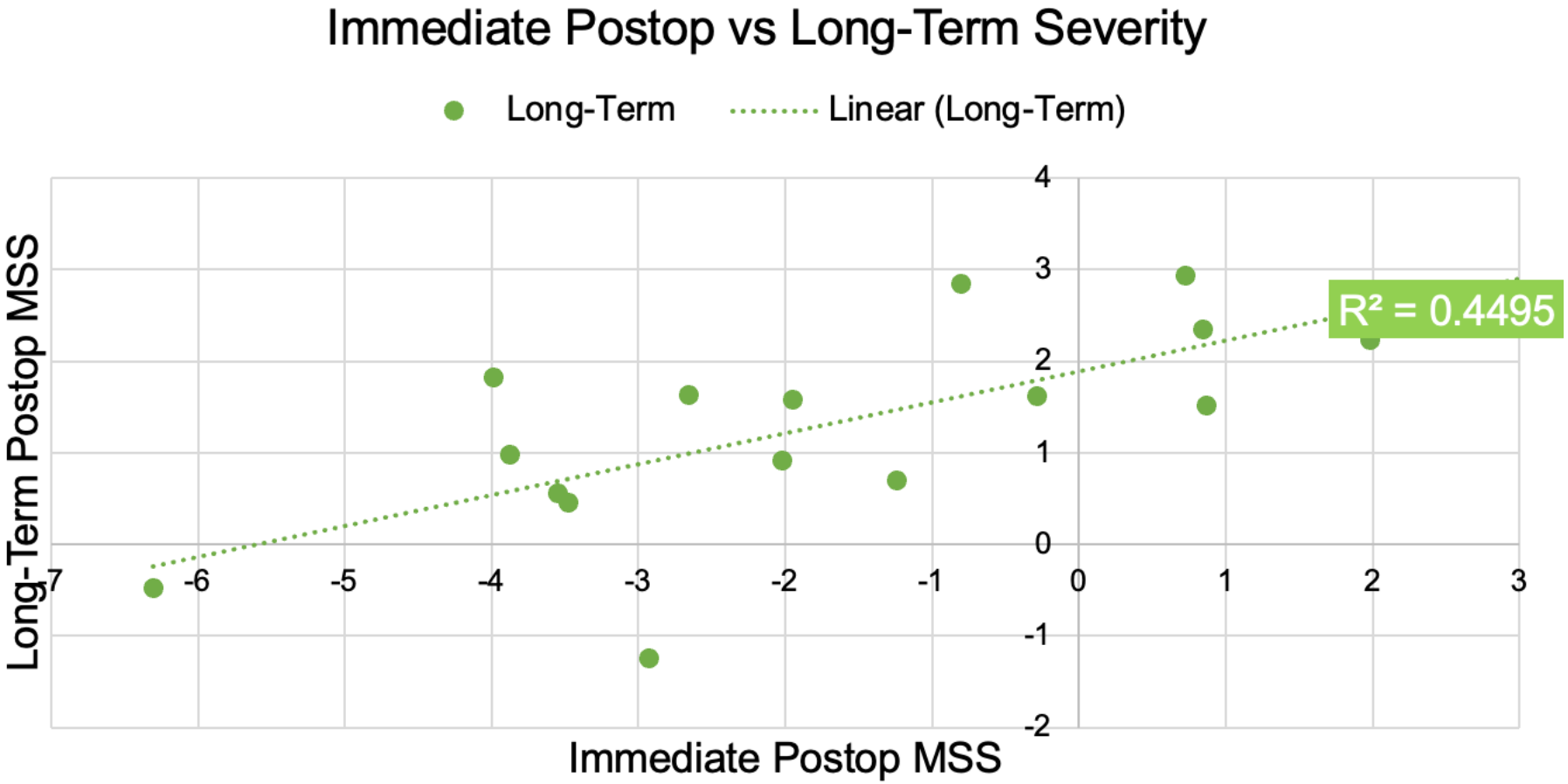
Degree of Overcorrection is positively correlated with more normal later term head shape



Degree of overcorrection correlates with late postoperative dysmorphology

(Berieger et al, CPCJ, in press)

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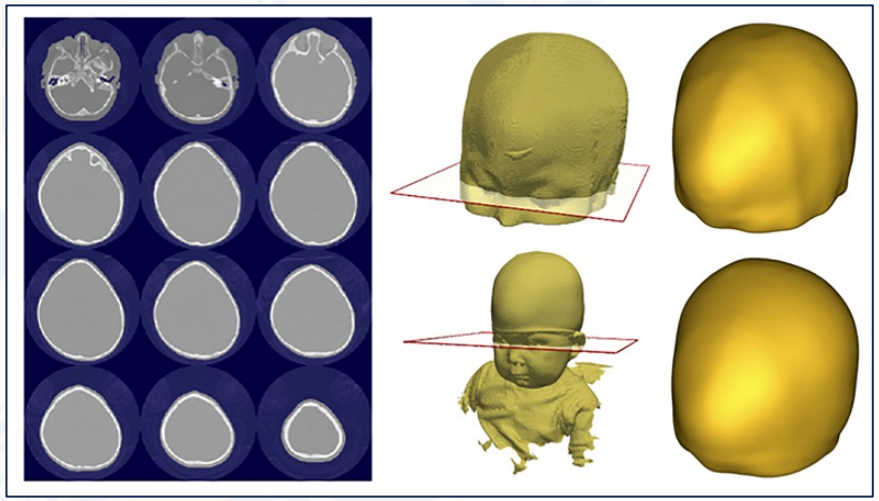
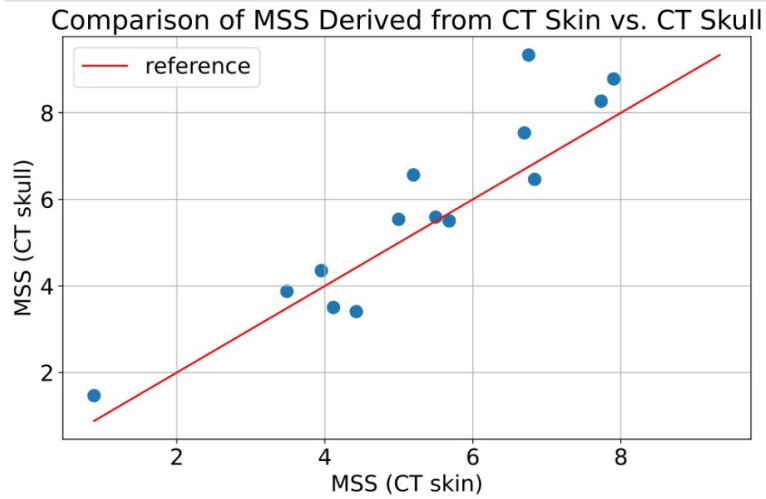
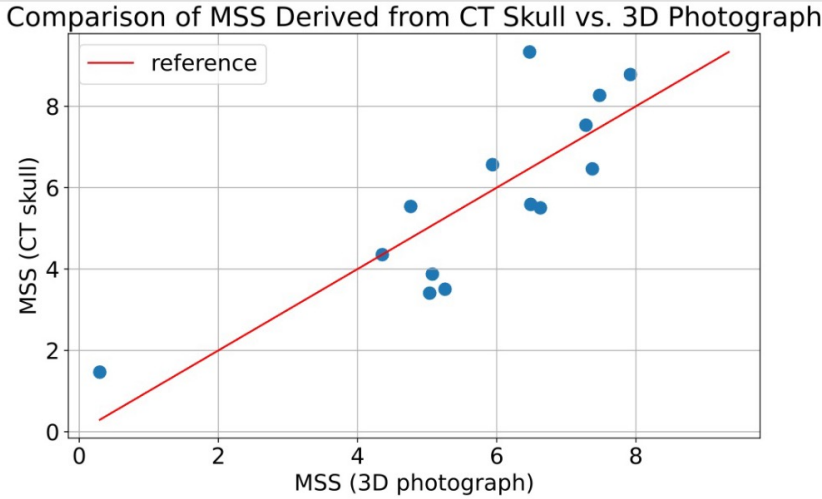
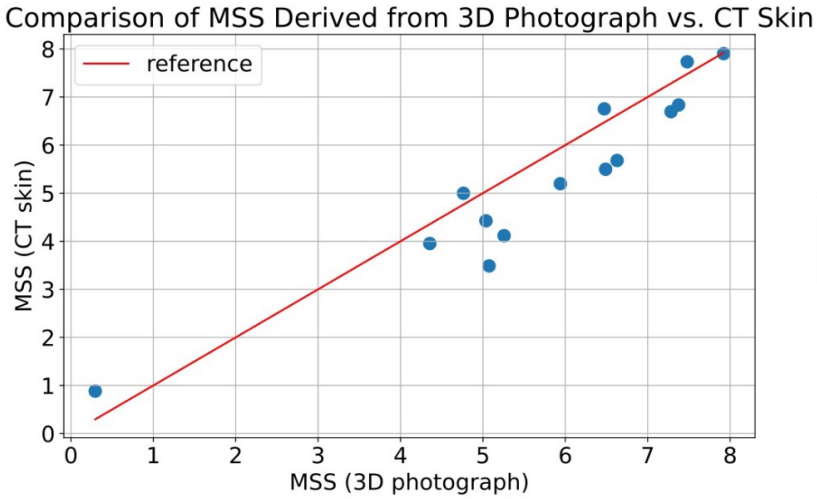
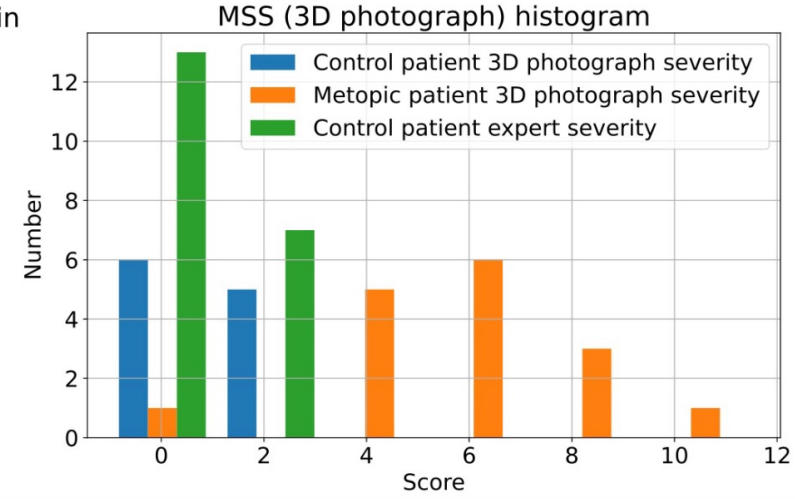
3D photographs are comparable to CTs for calculating MSS











Original Article

3D Photography to Quantify the Severity of Metopic Craniosynostosis

Madeleine K. Bruce, BA[1,#], Wenzheng Tao[2,#], Justin Beiriger, BSE[1], Cameron Christensen[2], Miles J. Pfaff, MD, MHS[1], Ross Whitaker, PhD[2], and Jesse A. Goldstein, MD[1]

The Cleft Palate Craniofacial Journal 2023, Vol. 60(8) 971–979

DOI: 10.1177/10556562211067071
journals.sagepub.com/home/cpc
Sage

(Bruce et al, CPCJ, 2023)

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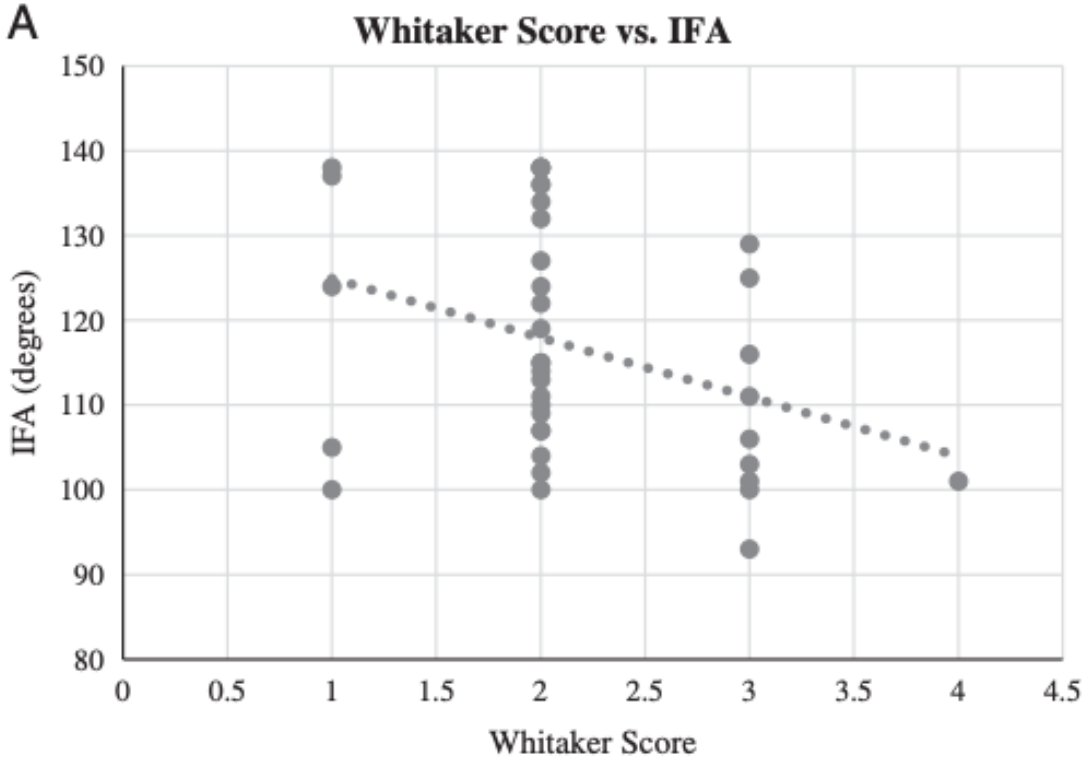
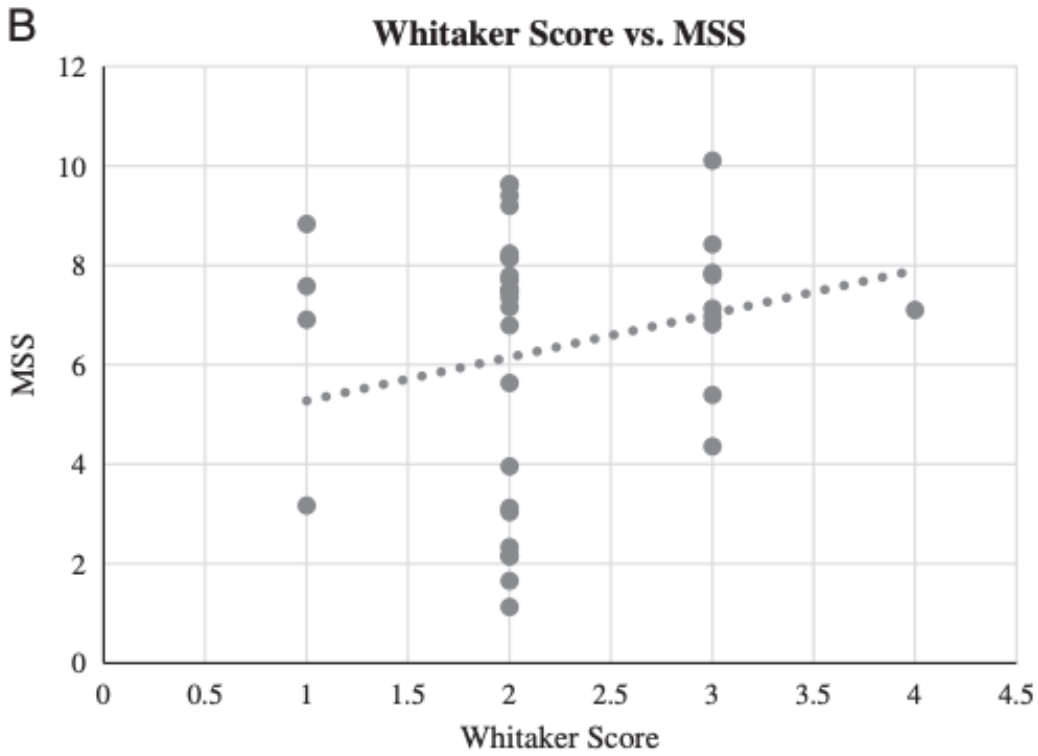
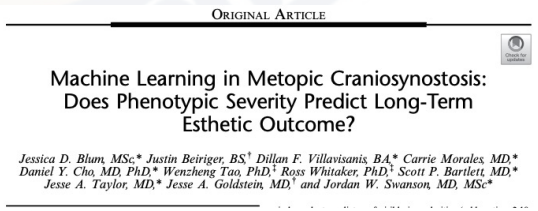
Whitaker scores were negatively correlated with IFA and positively correlated with MSS







ORIGINAL ARTICLE

Machine Learning in Metopic Craniosynostosis: Does Phenotypic Severity Predict Long-Term Esthetic Outcome?

Jessica D. Blum, MSc, Justin Beiriger, BS,† Dillan F. Villavisanis, BA,* Carrie Morales, MD,* Daniel Y. Cho, MD, PhD,* Wenzheng Tao, PhD,‡ Ross Whitaker, PhD,‡ Scott P. Bartlett, MD,* Jesse A. Taylor, MD,* Jesse A. Goldstein, MD,† and Jordan W. Swanson, MD, MSc**

(Blum et al, JCS, 2022)

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Higher MSS and CMD Scores Associated with Lower Neurocognitive Outcomes

Table 6. Correlation Coefficients and P-values for Severity Measures in Multivariable Linear Regression Models

Severity Measure	Endocranial Bifrontal Angle		Adjusted Endocranial Bifrontal Angle		Frontal Angle		Bitemporal Biparietal Diameter Ratio		**Metopic Severity Score**		**Cranial Morphology Deviation**	
Neurocognitive Test	B	p	B	p	B	p	B	p	B	p	B	p
Beery VMI-IV												
Visual Perception	-0.05	0.84	-0.03	0.90	-0.38	0.37	-70.88	0.18	-0.17	0.84	-0.03	0.57
Motor Coordination	0.20	0.60	0.12	0.77	-0.44	0.48	14.26	0.85	0.39	0.76	0.07	0.40
Visuomotor Integration	0.19	0.52	0.23	0.48	-0.24	0.61	50.55	0.54	-1.16	0.21	-0.07	0.23
KTEA-3												
Word Recognition	0.32	0.17	0.32	0.21	0.57	0.13	-42.03	0.36	-0.66	0.40	-0.04	0.38
Reading Comprehension	0.36	0.19	0.47	0.11	0.14	0.75	-26.50	0.64	**-1.78**	**0.040***	**-0.13**	**0.018***
Reading Composite	0.37	0.15	0.40	0.14	0.36	0.38	-42.25	0.42	**-1.86**	**0.024***	**-0.14**	**0.008***
Math Computation	-0.02	0.94	0.10	0.77	0.52	0.31	-97.94	0.12	-0.24	0.77	-0.01	0.85
Spelling	0.34	0.33	0.20	0.60	0.46	0.37	-92.87	0.17	-0.35	0.73	-0.02	0.72

Beery VMI-IV: Beery-Buktencia Developmental Test of Visuomotor Integration, 6th Edition; KTEA-3: Kaufman Test of Educational Achievement, 3rd Edition

Higher MSS and CMD scores correlated with lower reading comprehension and composite scores in school age children.

(Alperovich et al, PRS, 23)

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Point-of-Care Tool

User Pre-processing

Cloud

Upload

DICOM

Segmentation

Align

Anatomical plane

Crop

Region of interest

Shapeworks

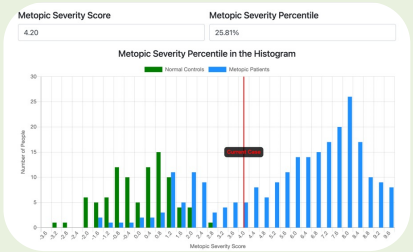
Statistical shape modeling

PCA

Shape descriptor

$$\begin{pmatrix} -0.9319 \\ -0.5529 \\ 0.7305 \\ 0.0594 \\ -0.5083 \\ -0.5604 \\ 0.9612 \\ 0.7647 \end{pmatrix}$$

Output

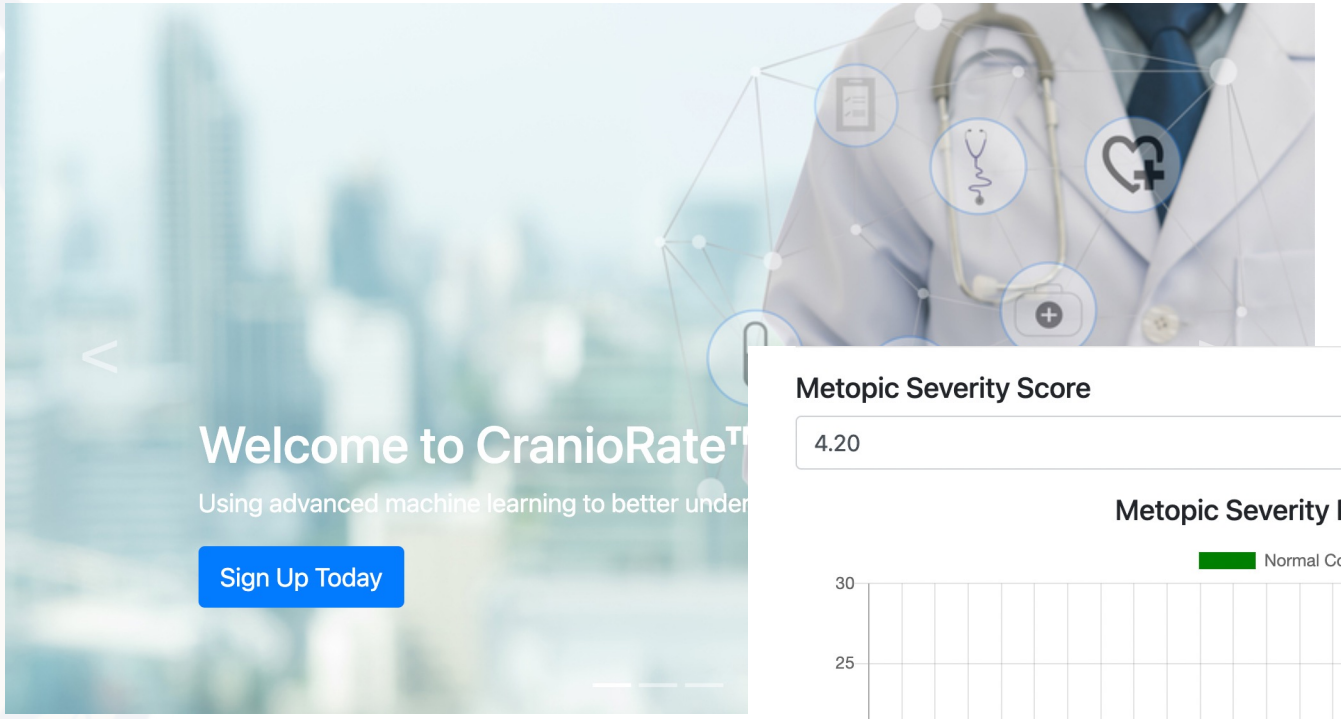


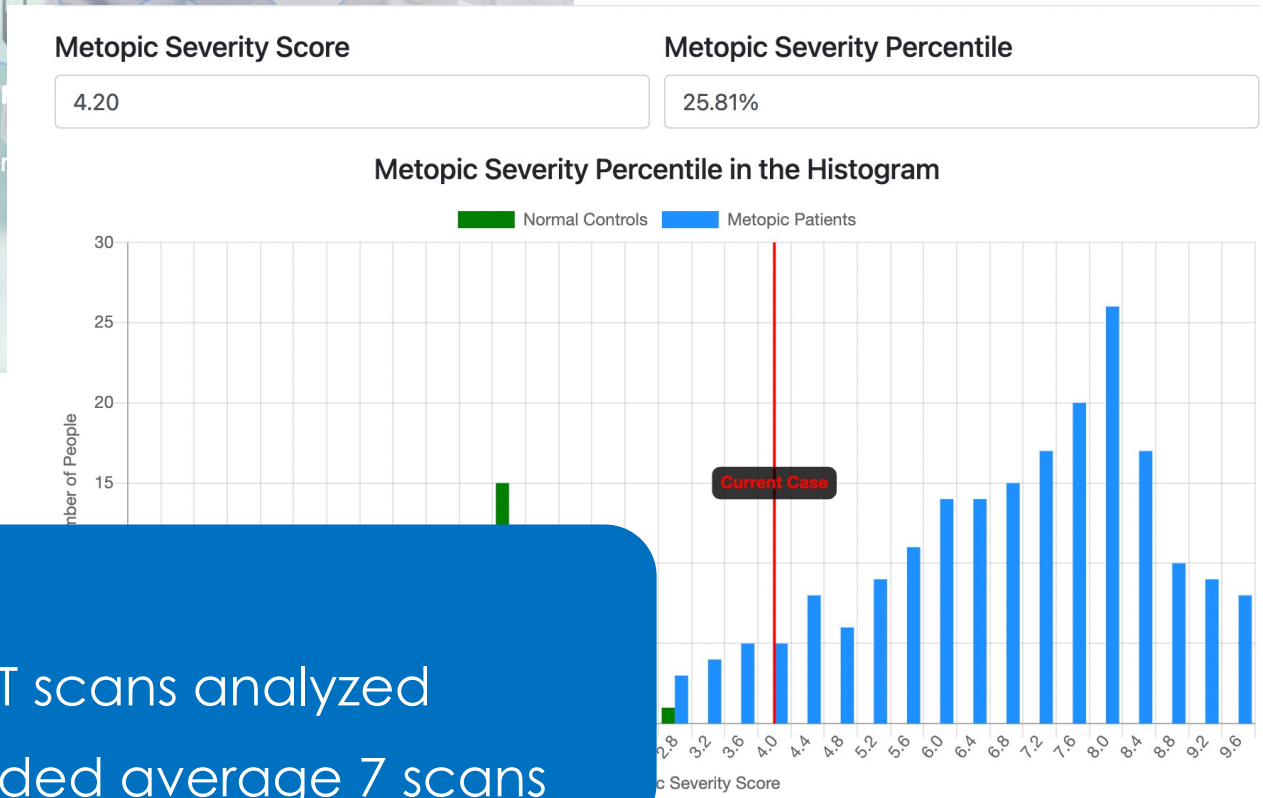
Analysis & Output

Cloud Processing

Point-of-Care Tool

CranioRate™





To date:

- Total of 743 CT scans analyzed
- 52 users uploaded average 7 scans

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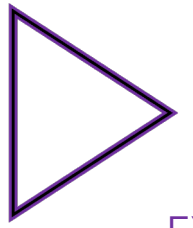
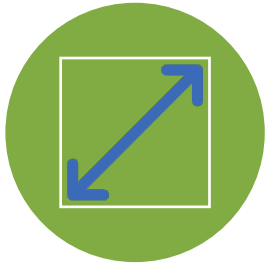
Current Aims

National Institutes of Health

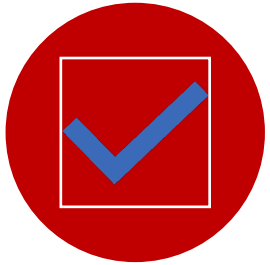
NIDCR - R01
FUNDING 2023-2028





EXPAND TO OTHER FORMS OF CRANIOSYNOSTOSIS

BUILD ASSOCIATIONS WITH CRITICAL CLINICAL FACTORS



DEVELOP ACCESSIBLE CRANIOSYNOSTOSIS IMAGEBANK

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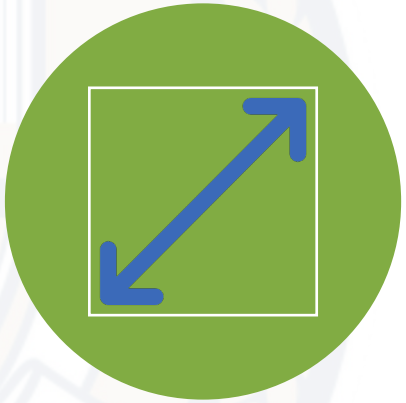
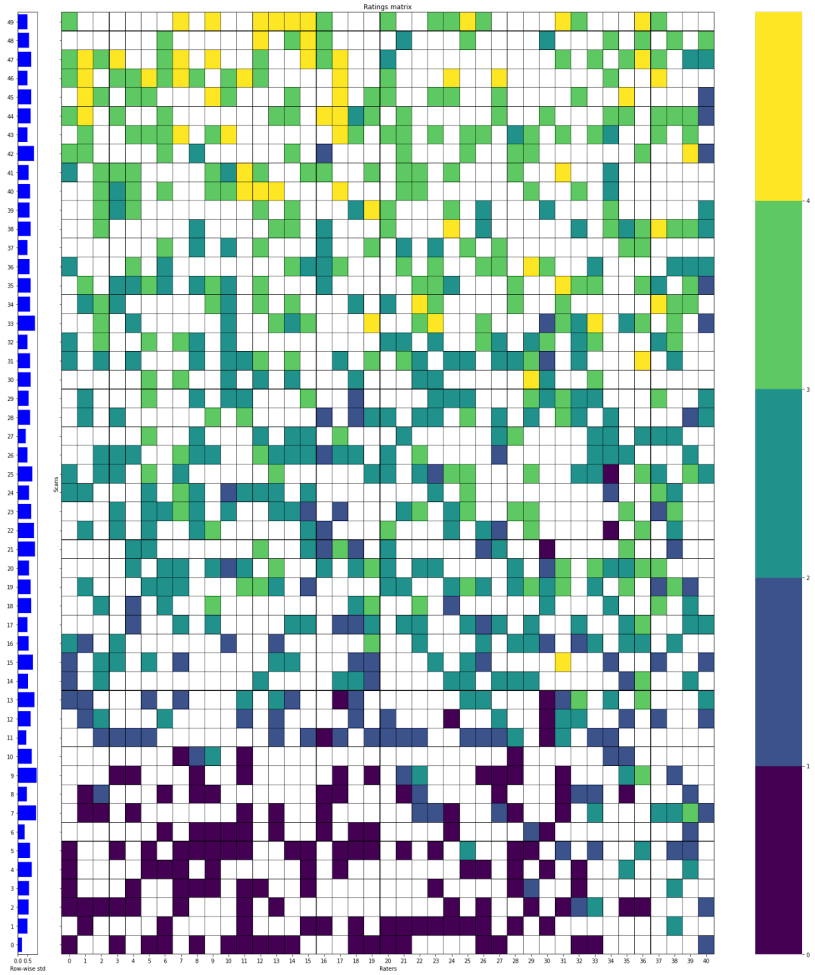
Current Aims - Scales



EXPAND TO OTHER FORMS OF CRANIOSYNOSTOSIS

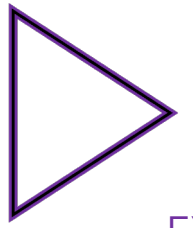


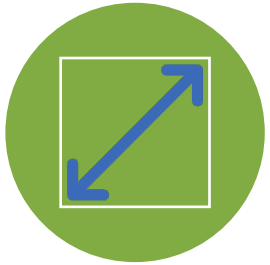
Sagittal Severity Scale under development

Current Aims

National Institutes of Health

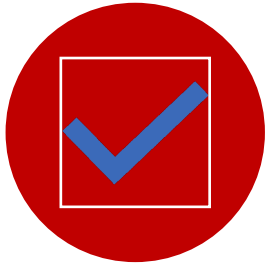
NIDCR - R01
FUNDING 2023-2028





EXPAND TO OTHER FORMS OF CRANIOSYNOSTOSIS

BUILD ASSOCIATIONS WITH CRITICAL CLINICAL FACTORS



DEVELOP ACCESSIBLE CRANIOSYNOSTOSIS IMAGEBANK

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Current Aims – Deep Phenotype

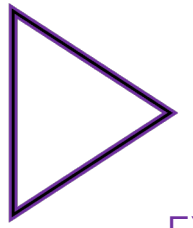
BUILD ASSOCIATIONS WITH CRITICAL CLINICAL FACTORS

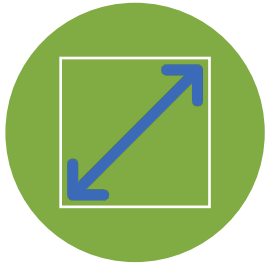
- Imaging (CT, MR, 3D photo)
- Shape model data
- Demographic data
- Pre-operative Neurocognative data
- Intervention type
- Comorbidities
- Genetic Triads (future)

Current Aims

National Institutes of Health

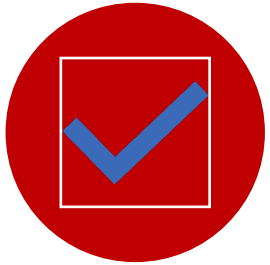
NIDCR - R01
FUNDING 2023-2028





EXPAND TO OTHER FORMS OF CRANIOSYNOSTOSIS

BUILD ASSOCIATIONS WITH CRITICAL CLINICAL FACTORS

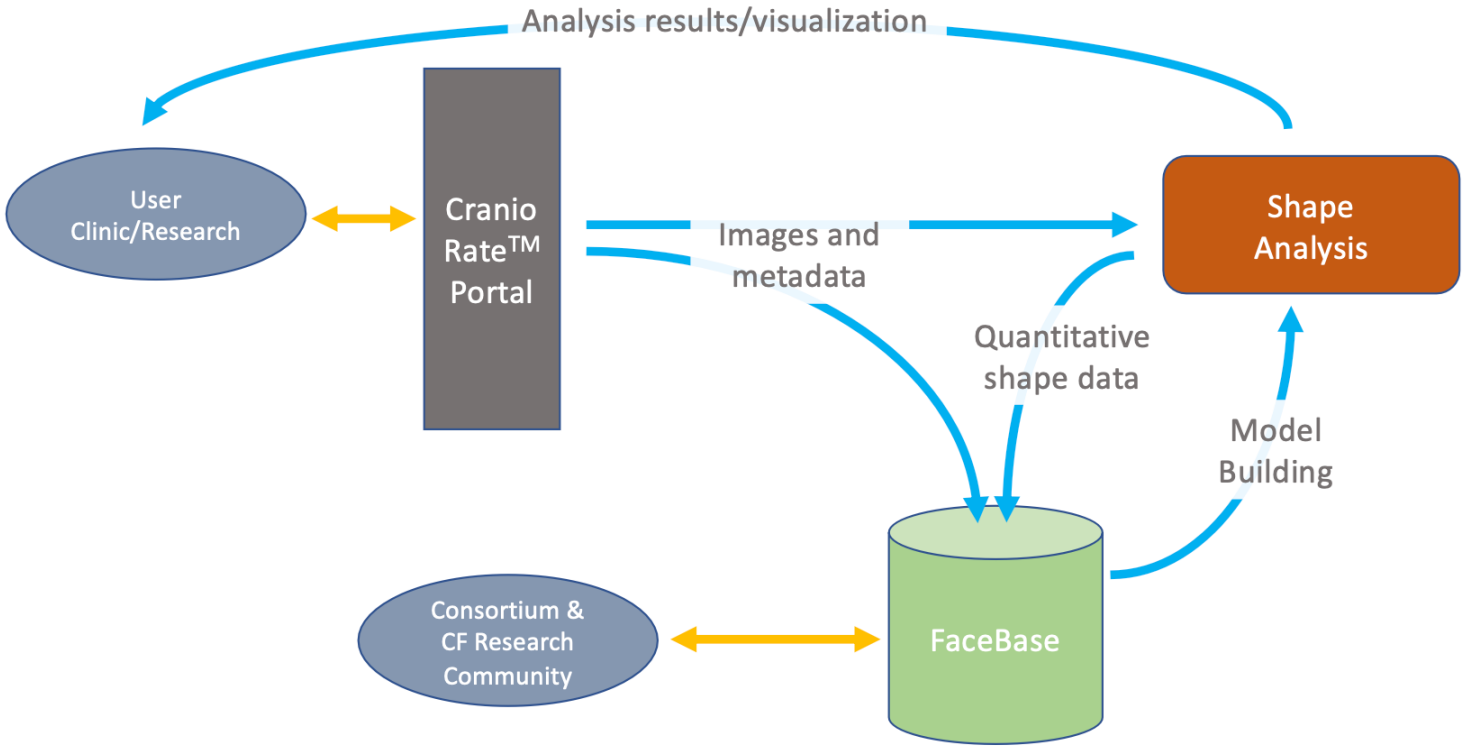


DEVELOP ACCESSIBLE CRANIOSYNOSTOSIS IMAGEBANK

Children's Hospital of Pittsburgh of UPMC

Current Aims – Data Movement

DEVELOP ACCESSIBLE CRANIOSYNOSTOSIS IMAGEBANK



Proposed movement of data

Current Aims – Consortium

DEVELOP ACCESSIBLE CRANIOSYNOSTOSIS IMAGEBANK

Develop Core and Extended Consortia of Collaborators

	IRB	DUA	Ready to Share
VANDERBILT			
WASHINGTON UNIVERSITY, ST. LOUIS	✓	✓	✓
CHILDREN'S HOSPITAL OF PHILADELPHIA	✓	✓	✓
ALDER HEY	✓	✓	
ERASMUS	✓	✓	
CHILDREN'S HOSPITAL OF LOS ANGELES			
UNIVERSITY OF CALIFORNIA, SAN DIEGO		✓	
SEATTLE CHILDREN			
UNIVERSITY OF ILLINOIS CHICAGO	✓	✓	
ELES			
N		✓	
AL CENTER	✓	✓	✓
CAL CENTER			
DES			
JOHN HOPKINS HOSPITAL			
ASAN MEDICAL CENTER			
UNIVERSITY HOSPITAL BASEL			
NECKER UNIVERSITY HOSPITAL			
UNIVERSITY OF WARMIA AND MAZURY IN OLSZTYN			
LUIRE CHILDREN HOSPITAL			
SEMMELWEIS UNIVERSITY			
WAKE FOREST	✓	✓	✓
YALE	✓	✓	✓
SHRINERS	✓	✓	

Currently: 30 Collaborators (US and International)

- 5 ready to transfer data
- 6 close

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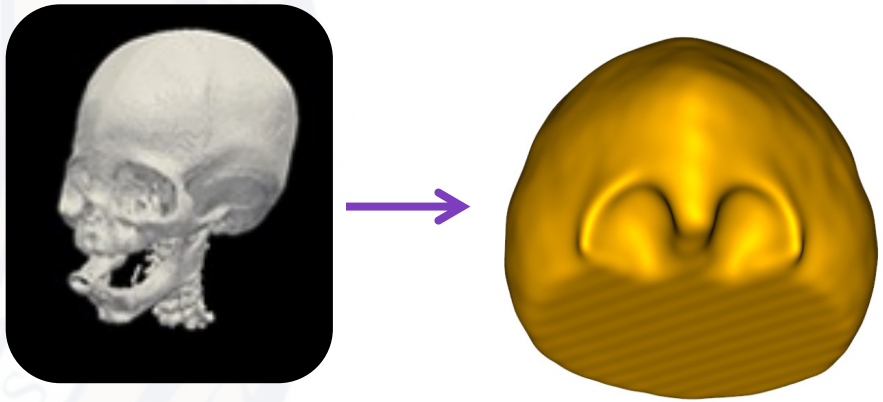
Human Subjects protection

Imaging Data

CT and MR images



3D photogrammetry

Clinical Data

- De-identified
- Relative (not absolute) dates
- One-way encryption/hashing

IRB Schema

Retrospective Arm	Extended Consortium sites (currently 25+)	No consent/ recruitment	Imaging plus pertinent demographic and medical data (i.e. age at scan, gender, race, diagnosis, etc),	No neurocognitive data
Prospective Arm	4 Core Consortium Sites	Recruit/ consent patients	Imaging plus pertinent demographic and medical data (i.e. age at scan, gender, race, diagnosis, etc),	Pre-operative neurocognitive data.

The CranioRate™ Team

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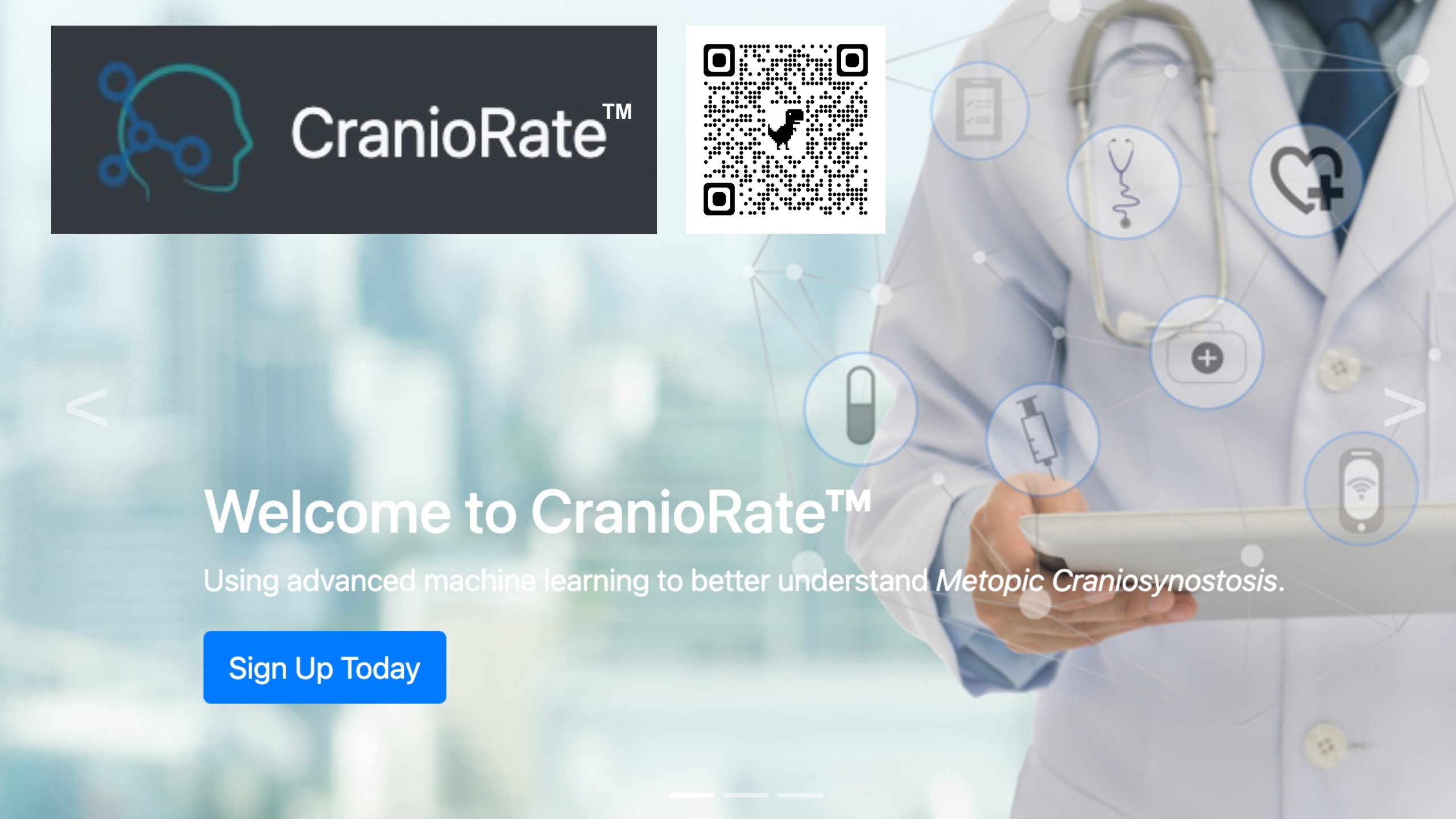
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