Using AI to personalize and optimize the treatment of craniosynostosis

Antonio R. Porras, PhD

Assistant Professor

Department of Biostatistics and Informatics, Colorado School of Public Health
Departments of Pediatrics, Surgery and Biomedical Informatics, School of Medicine
University of Colorado Anschutz Medical Campus

Department of Pediatric Neurosurgery
Children's Hospital Colorado

Research Director

Department of Pediatric Plastic & Reconstructive Surgery
Children's Hospital Colorado

University of Colorado Anschutz Medical Campus

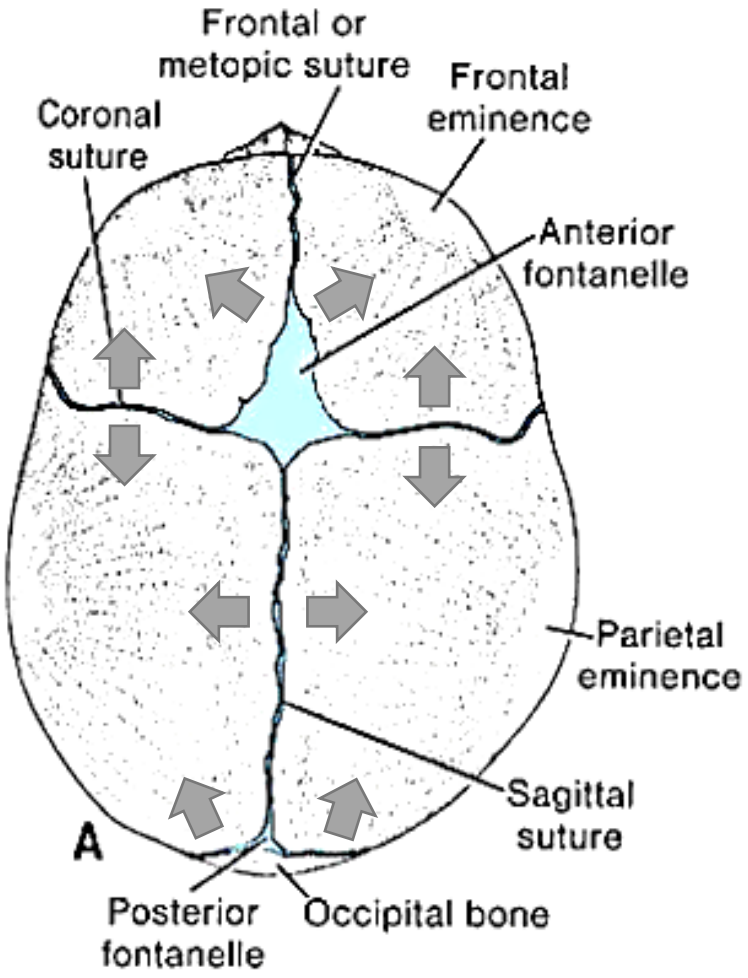
colorado school of public health

UNIVERSITY OF COLORADO
COLORADO STATE UNIVERSITY
UNIVERSITY OF NORTHERN COLORADO

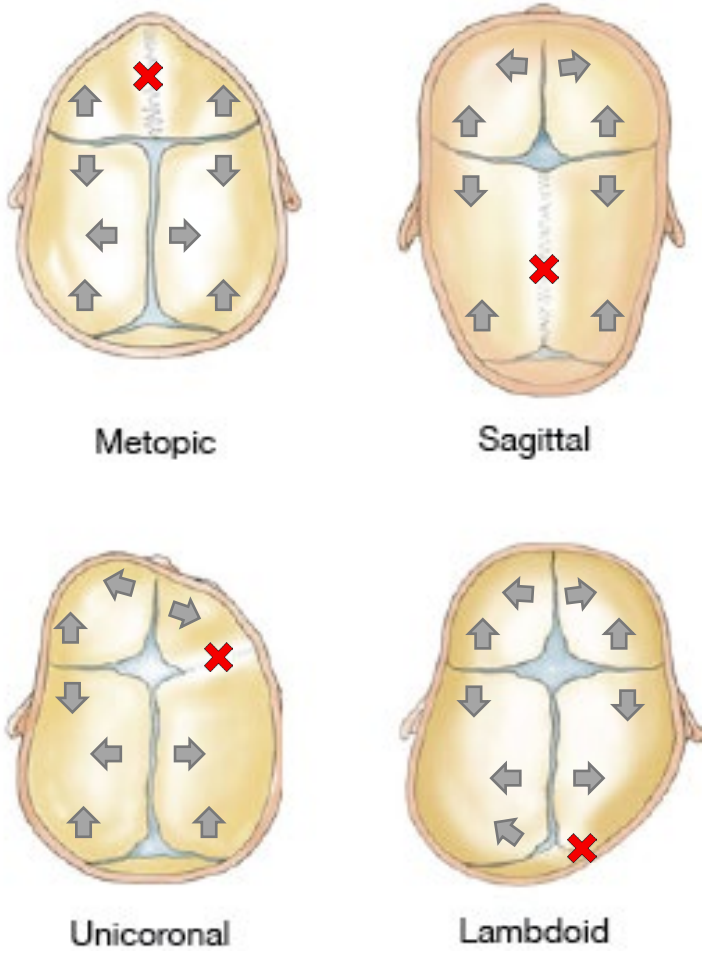
Children's Hospital Colorado

Craniosynostosis

- **Early fusion of one or more cranial sutures.** It affects ~1 in 1,600 - 1,800 live births.

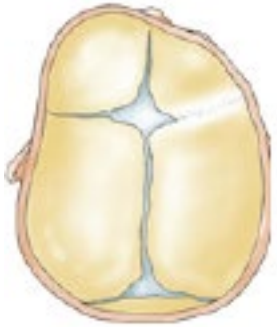


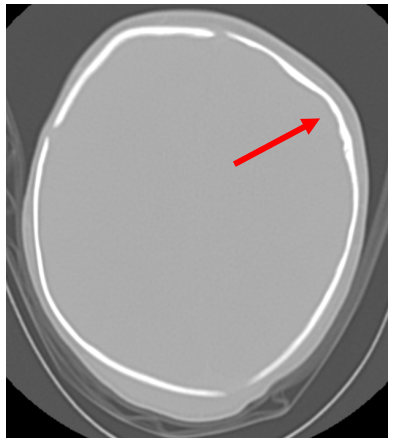
Single suture fusion



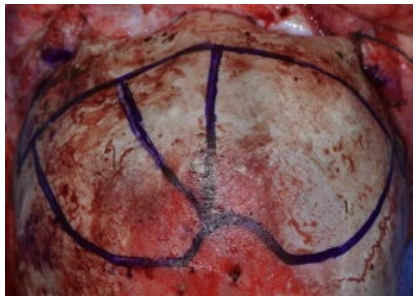
Traditional management of craniosynostosis

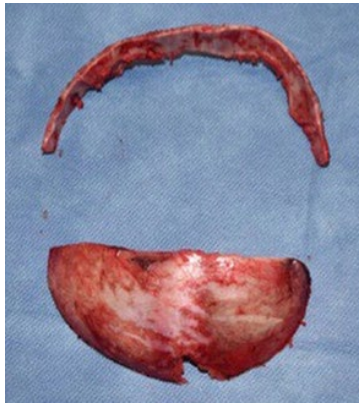
Pre-surgical evaluation



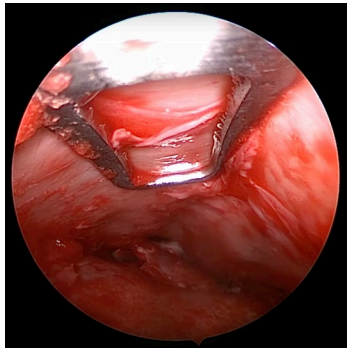


Open surgery

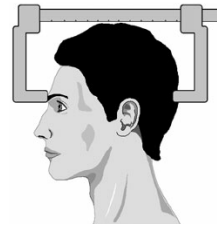


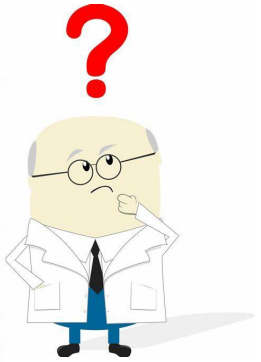


Endoscopic surgery



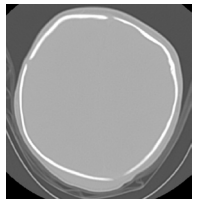
Post-surgical evaluation



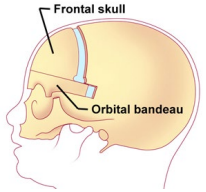


Our previous work

Pre-surgical evaluation



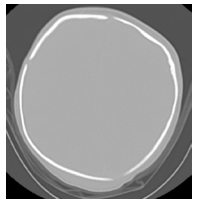
Treatment



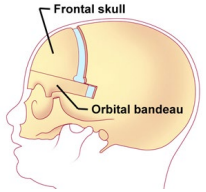
Post-surgical evaluation

Our previous work

Pre-surgical evaluation

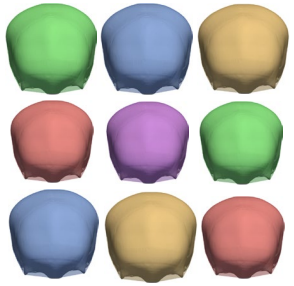


Treatment



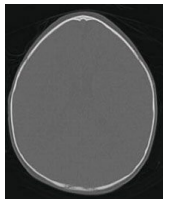
Post-surgical evaluation

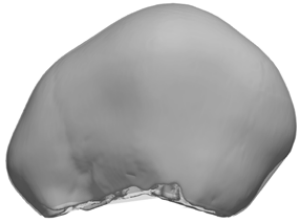
Normative database



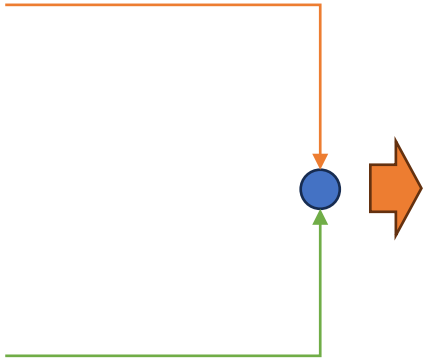
Normative cranial shape variability

Patient

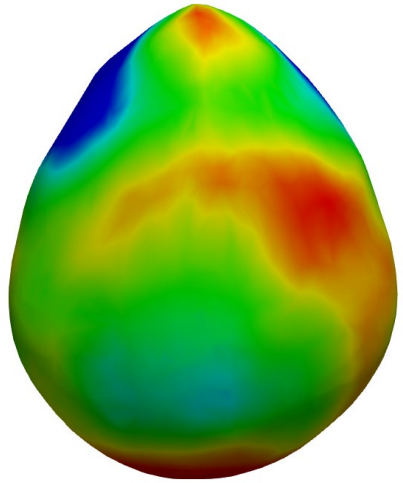




Cranial shape



Anterior



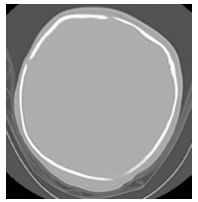
Posterior

Malformations

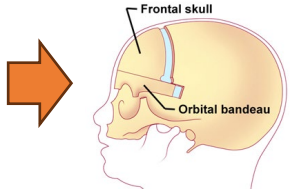
[Mendoza et al, Personalized assessment of craniosynostosis via statistical shape modeling, Med Imag Anal, 2014]

Our previous work

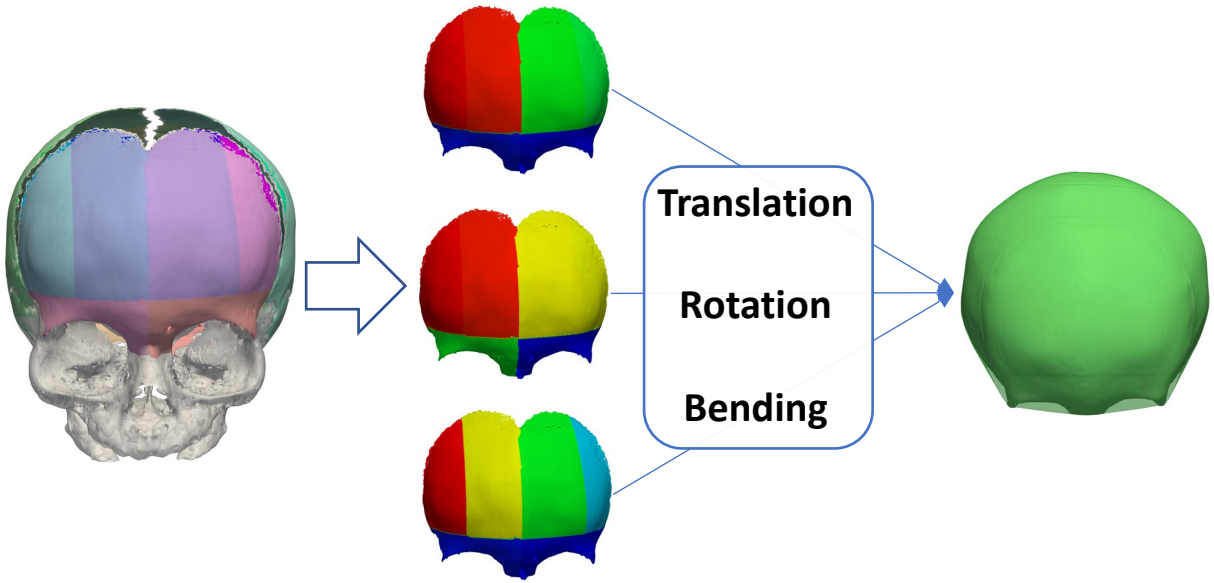
Pre-surgical evaluation



Treatment

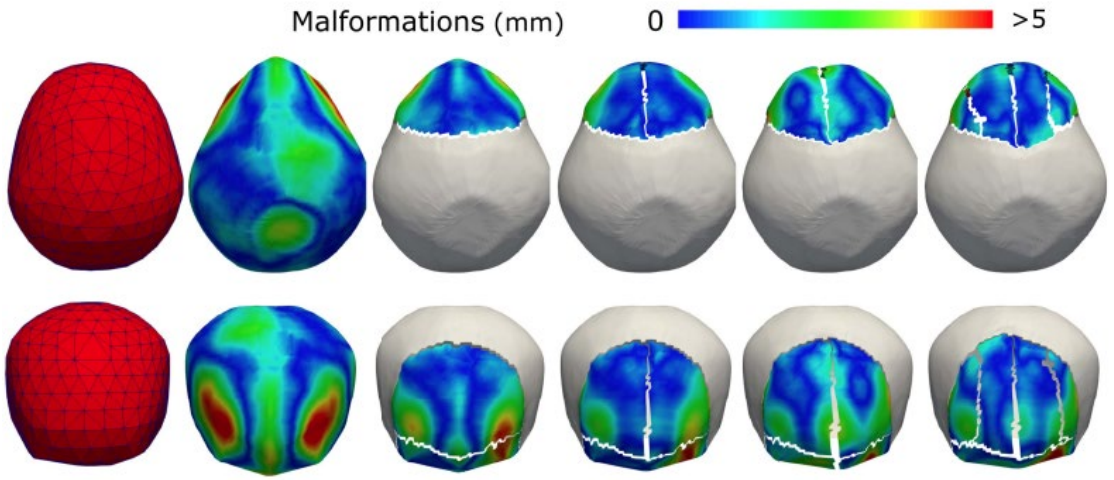


Post-surgical evaluation



Personalized osteotomy alternatives

Optimal outcome

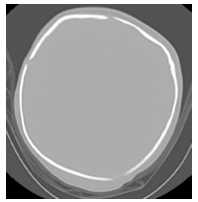


Personalized reference | Patient | Plan 1 | Plan 2 | Plan 3 | Plan 4

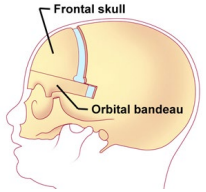
[Porras et al, Locally Affine Diffeomorphic Surface Registration and Its Application to Surgical Planning of Fronto-Orbital Advancement, IEEE Trans Med Imag, 2018]

Our previous work

Pre-surgical evaluation

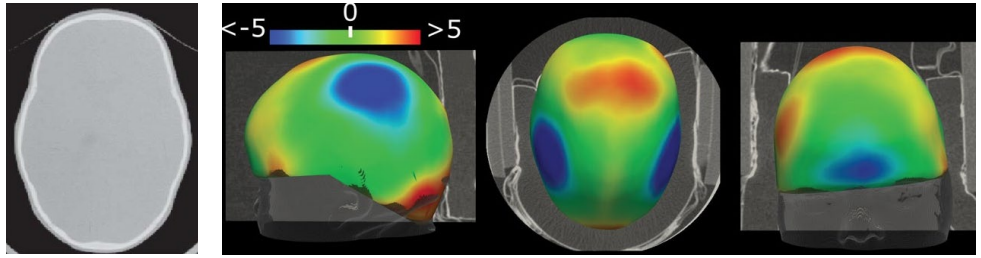


Treatment



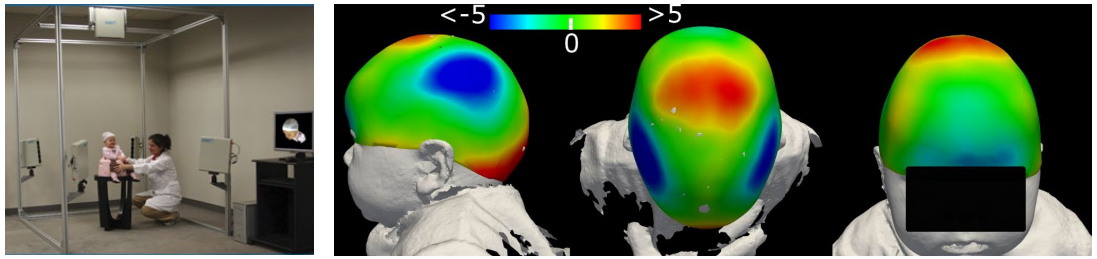
Post-surgical evaluation

CT



=

3D photogrammetry



Craniosynostosis identification

- 95% sensitivity, 96% specificity

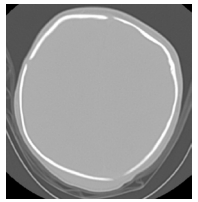
Identification of single fused suture

- Sagittal: 100% sensitivity, 99% specificity
- Unicoronal: 100% sensitivity, 99% specificity
- Metopic: 94% sensitivity, 100% specificity

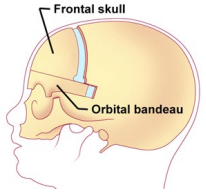
[Porras et al., Quantification of Head Shape from Three-Dimensional Photography for Presurgical and Postsurgical Evaluation of Craniosynostosis, Plast Reconst Surg, 2019]

Challenges

Pre-surgical evaluation



Treatment

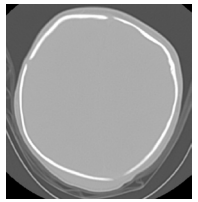


Post-surgical evaluation

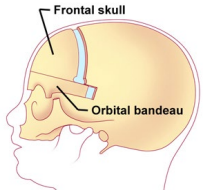
- Cannot quantify local volumetric anomalies in the context of age and sex
- Pre-surgical evaluations are not accurate at the time of surgery
- Post-surgical evaluation cannot be contextualized and interpreted

Challenges

Pre-surgical evaluation



Treatment

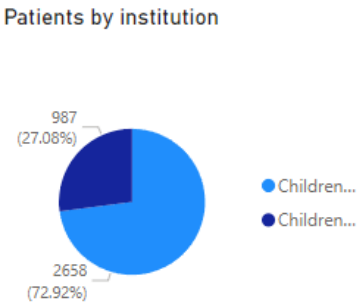


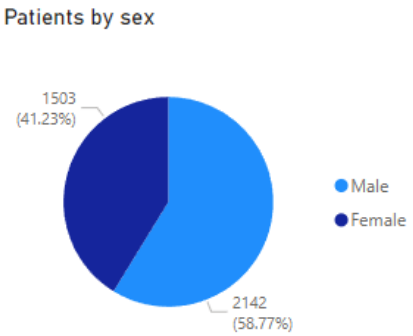
Post-surgical evaluation

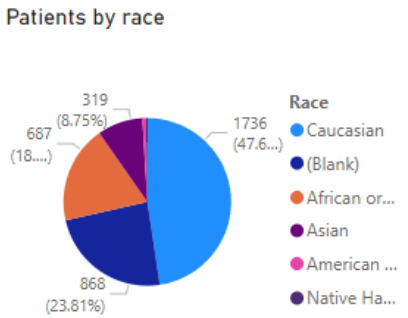
Craniosynostosis is a developmental disorders and must be studied as such

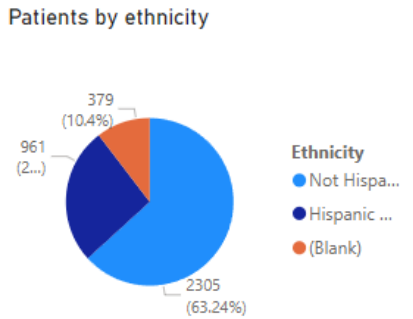
Children's Hospital Colorado

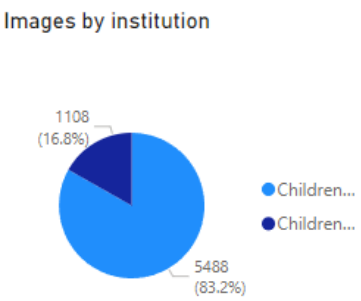
Children's National

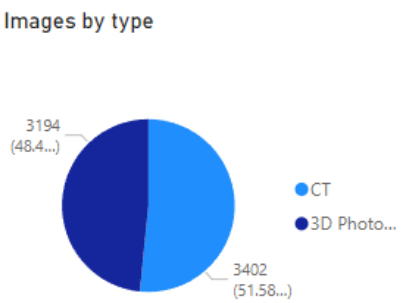


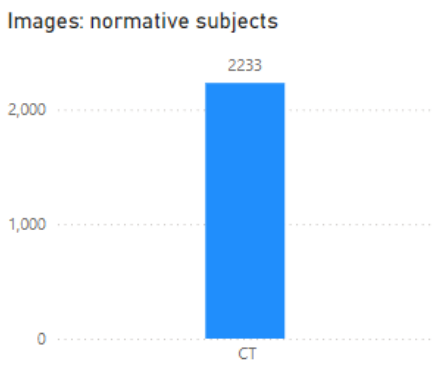


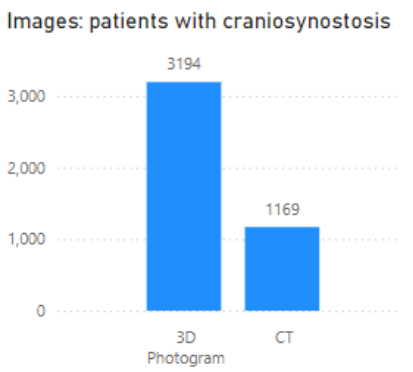






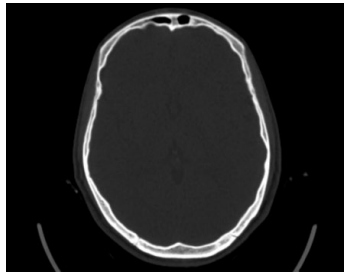


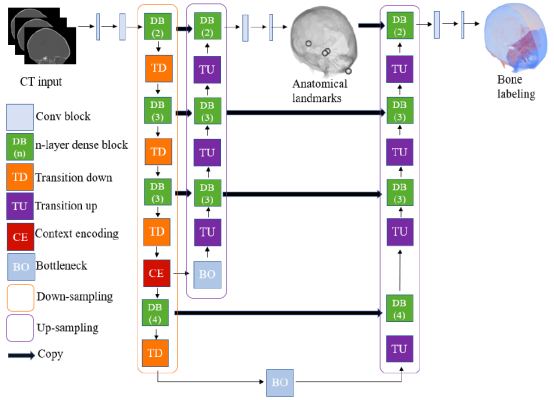




AI can learn personalized growth without longitudinal data

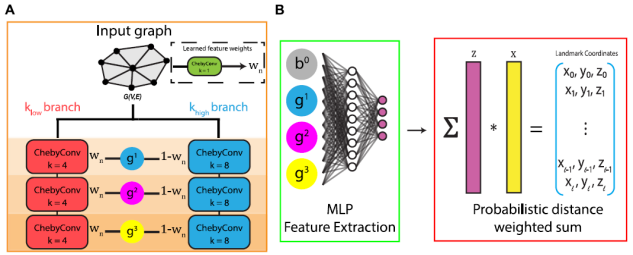
CT





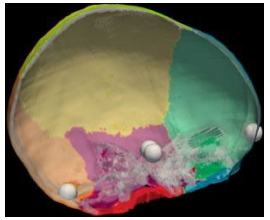
[Liu et al, MICCAI, 2022] [Liu et al, IEEE Tans Med Imag, 2023]

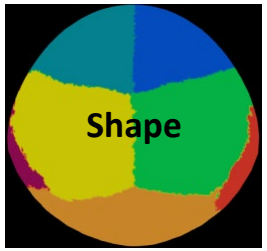
3D Photogrammetry

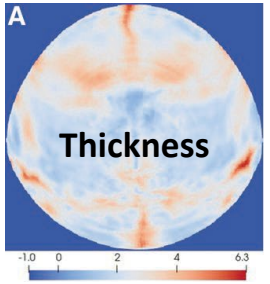


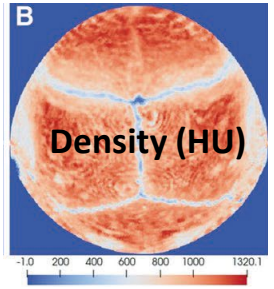
[Elkhill et al, MICCAI, 2022] [Elkhill et al, Comp Meth Prog Biomed, 2023]

Standardization

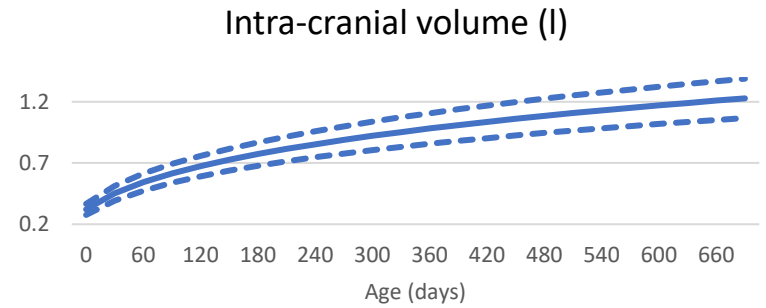


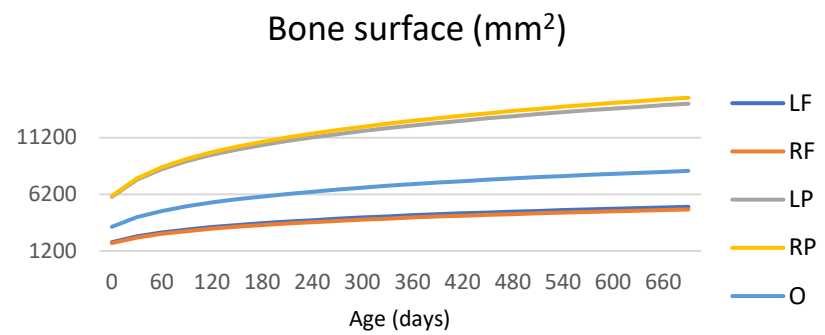


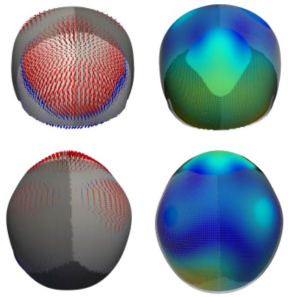




Personalized growth predictions







Predictive error: **1.36 +- 0.61 mm**

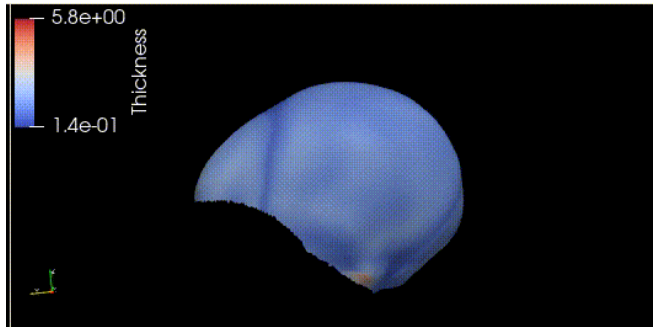
Voxel spacing: 1.69 mm

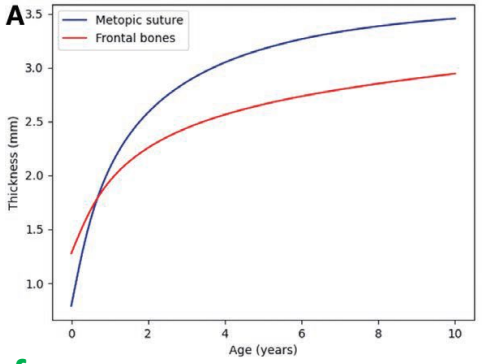
[Porras et al, IEEE Trans Biomed Eng, 2022]

Developmental modeling

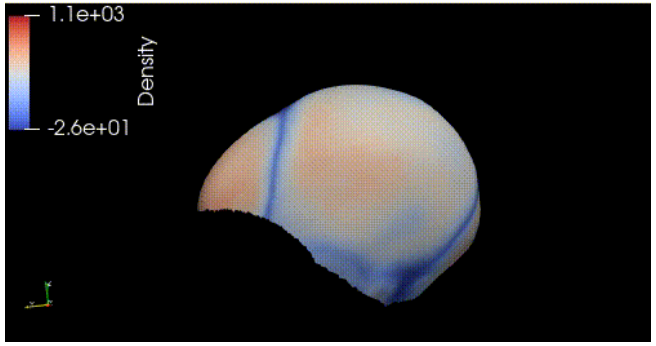
Normative reference model

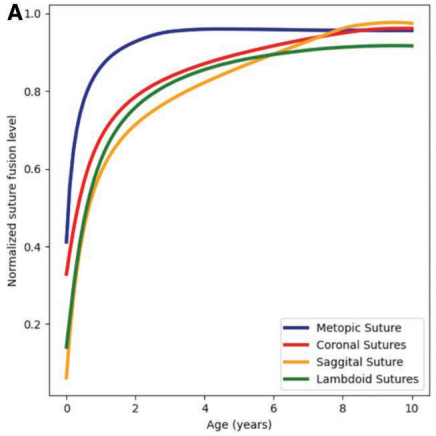
Local thickness reference





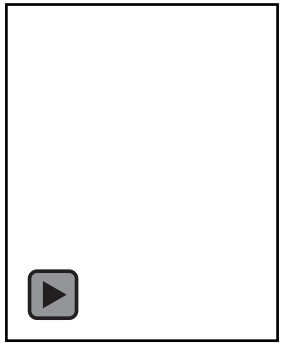
Local density reference



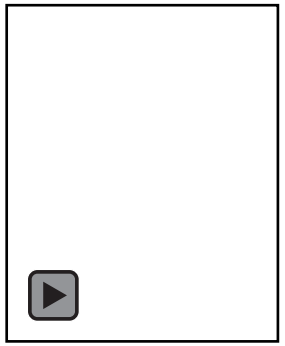


[Liu et al, Data-driven Normative Reference of Pediatric Cranial Bone Development, Plast Rec Surg GO, 2022]

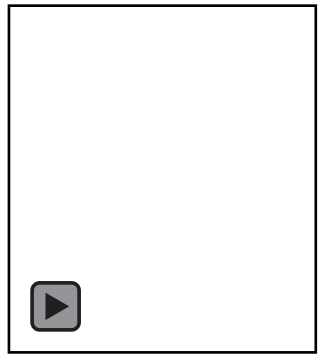
Predictive model of craniosynostosis



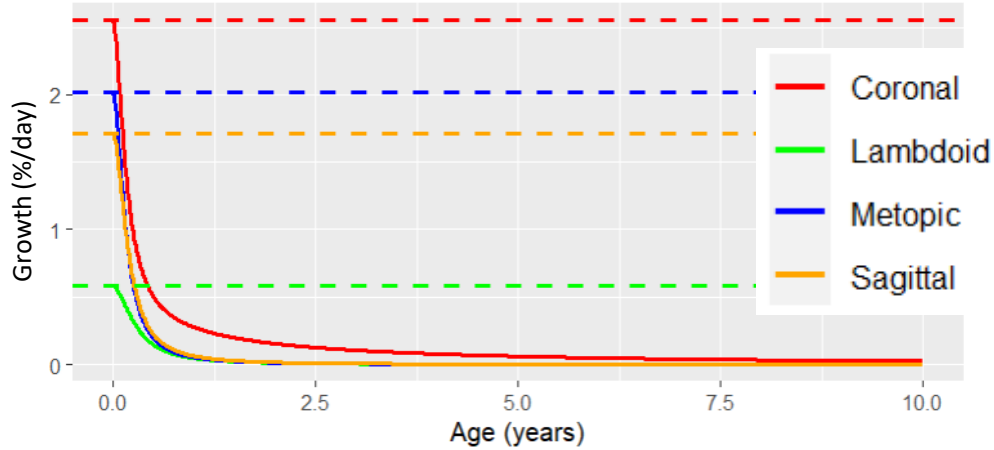
Metopic



Sagittal



Right coronal

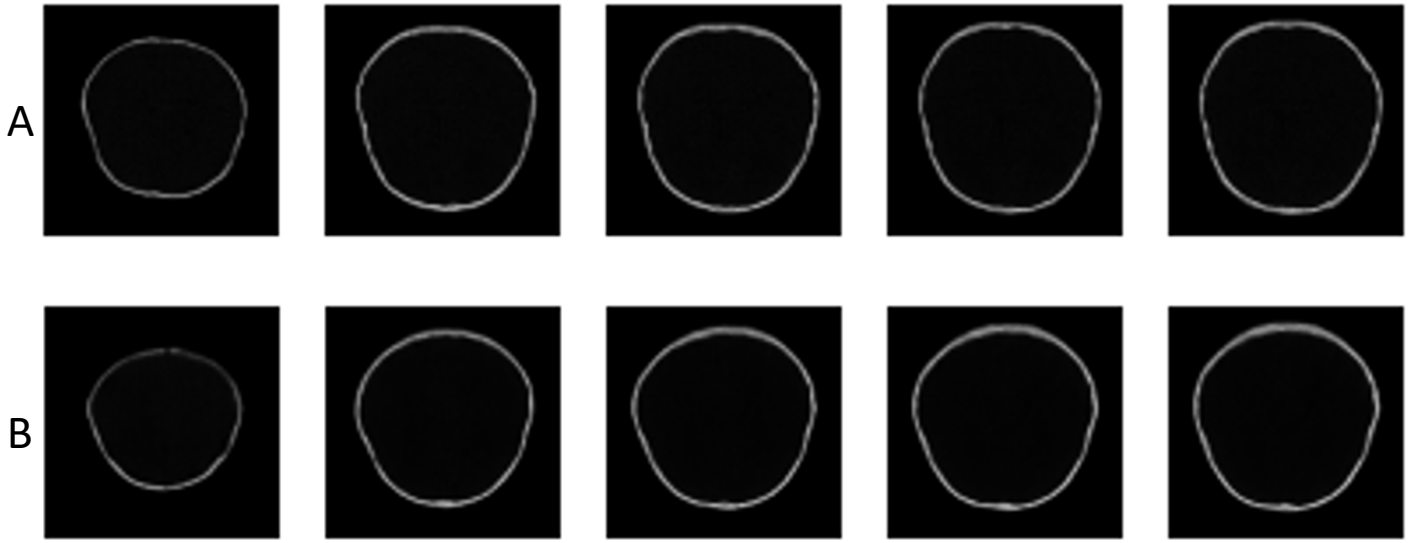


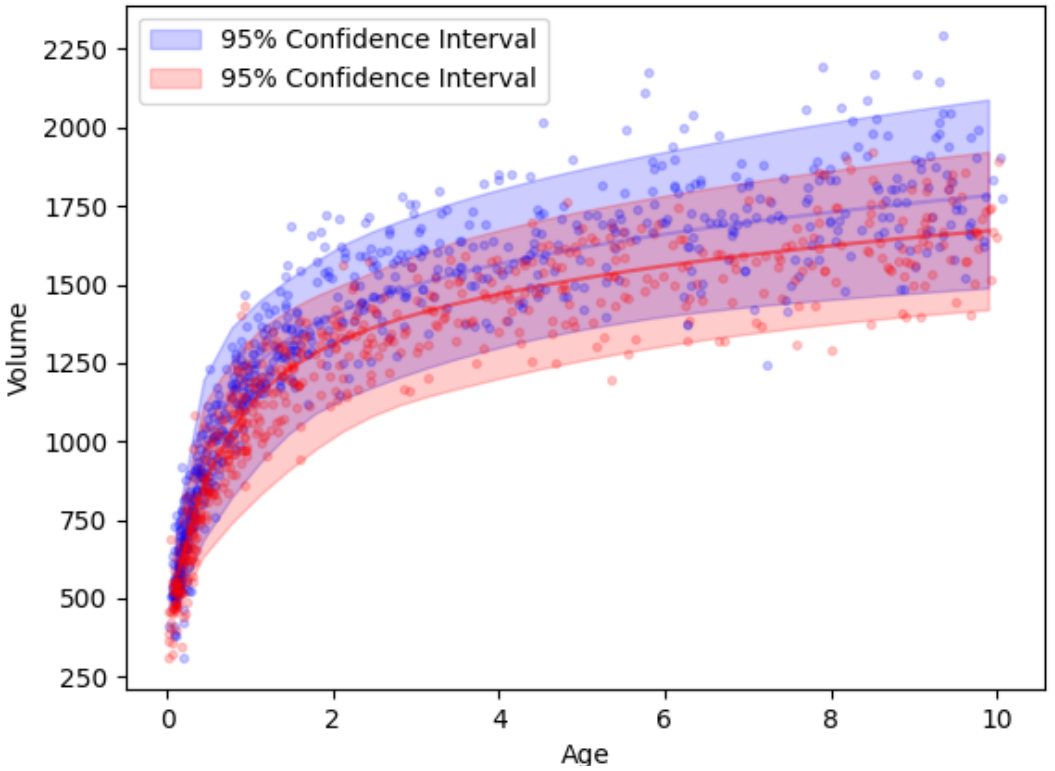
[Liu et al, Data-driven cranial suture growth model enables predicting phenotypes of craniosynostosis, Sci Rep, 2023]

Developmental generative modeling

Method	PSNR	Shape distance (mm)	Volume difference (L)
cGAN	22.41 ± 3.91*	7.54 ± 4.05*	0.28 ± 0.22*
cVAE	22.32 ± 3.82*	6.62 ± 3.41*	0.24 ± 0.20*
AB-GAN	25.41 ± 2.28*	6.39 ± 3.36*	0.27 ± 0.19*
Baseline	24.06 ± 3.01*	5.92 ± 2.96*	0.20 ± 0.17*
TID-GAN	25.22 ± 2.35	4.89 ± 2.76*	0.16 ± 0.12*
REC-GAN	25.52 ± 2.33	4.92 ± 3.01*	0.18 ± 0.11*
Proposed	**25.55 ± 2.21**	**4.66 ± 2.66**	**0.14 ± 0.12**

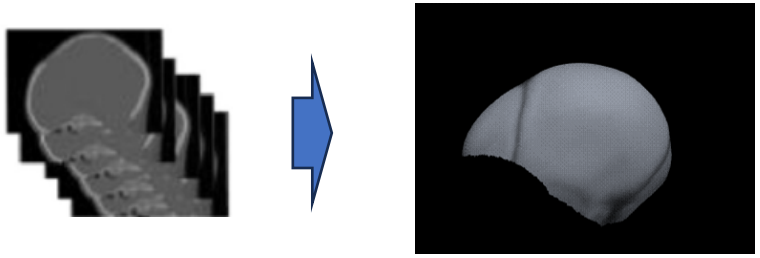
* statistical significance





Quantitative characterization of development

Reference of development

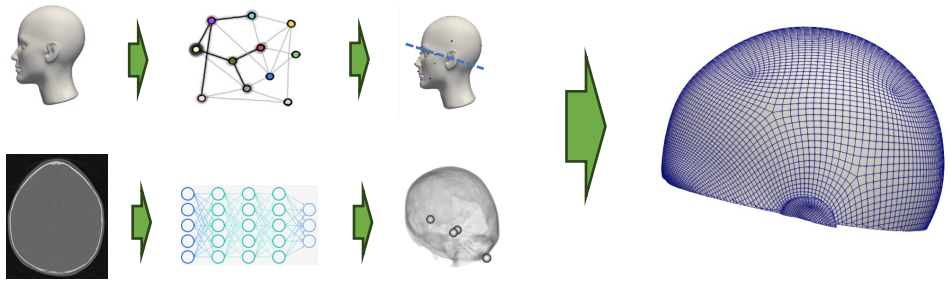


Real-time anatomy standardization

3D photogrammetry

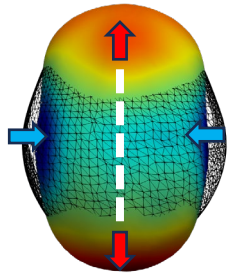
or

CT imaging

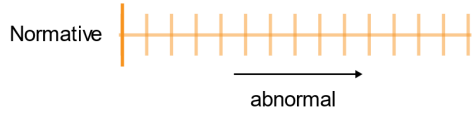


AI

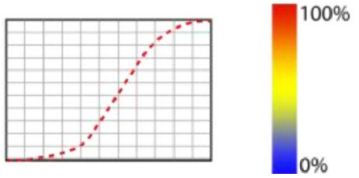
Local **volume** anomalies (ml)



Head **shape** anomaly (HSA) index



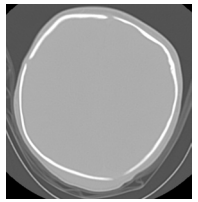
Craniosynostosis phenotype risk score (CRS)

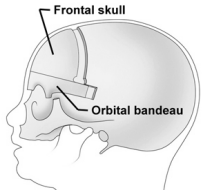


[Elkhill et al, Geometric learning and statistical modeling for surgical outcomes evaluation in craniosynostosis using 3D photogrammetry, Comp Meth Prog Biomed, 2023]

Our previous work

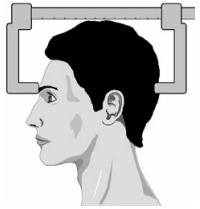
Pre-surgical evaluation → Treatment → Post-surgical evaluation

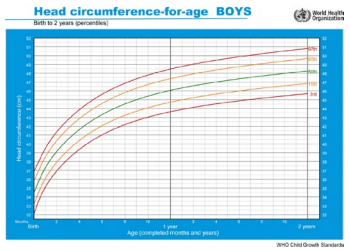




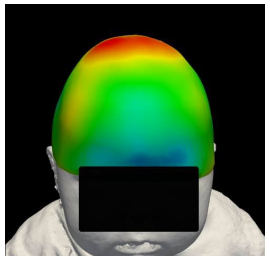
Evaluation of cranial growth

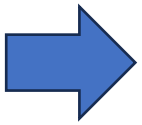
- Current: simple non-descriptive metrics





- Ongoing research

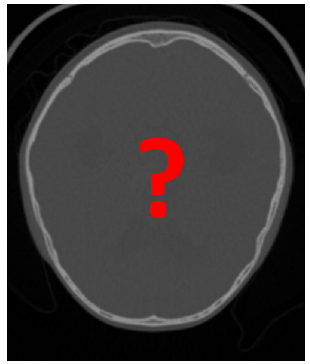




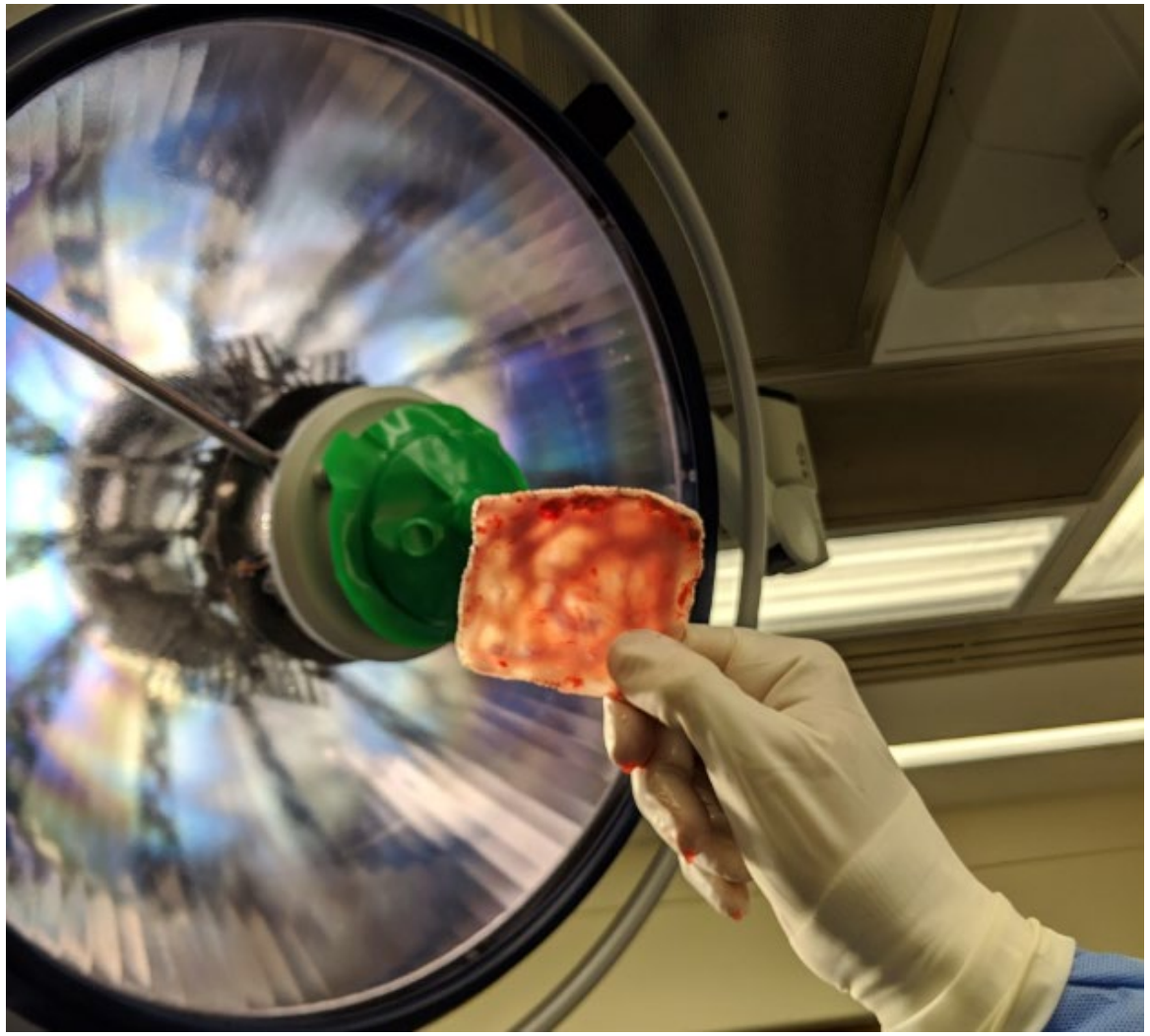
NIH National Institute of Dental and Craniofacial Research

Evaluation of increased intracranial pressure

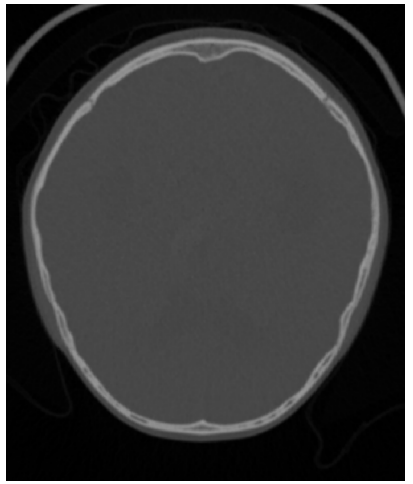
- Subjective evaluation of unspecific symptoms of **chronic** or **non-acute** intracranial pressure increase



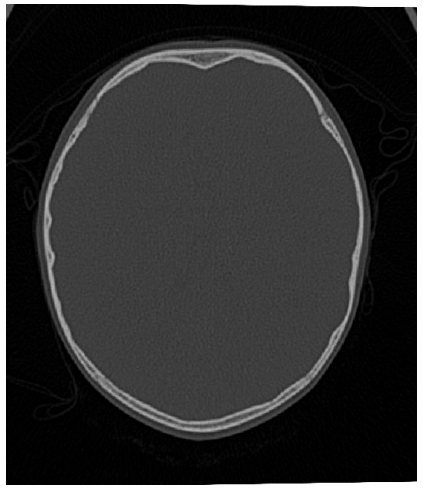
Identification of increased intracranial pressure



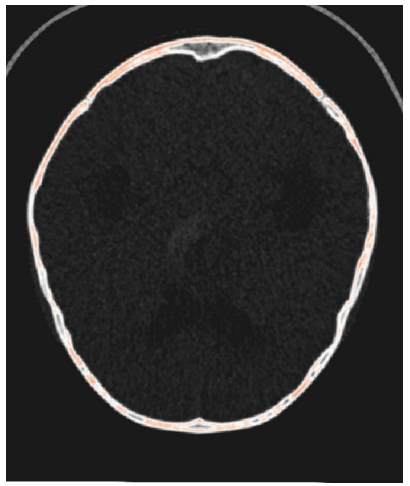
ICH - neoplasm

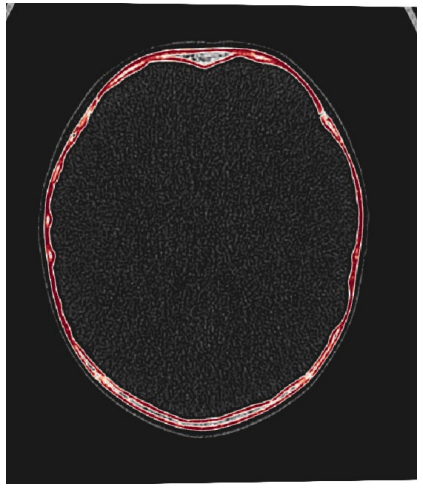


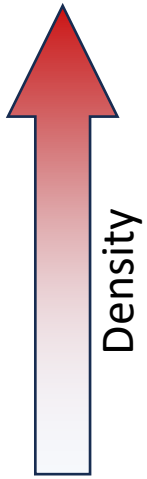
Normative



Male, 7 years and 8 months old

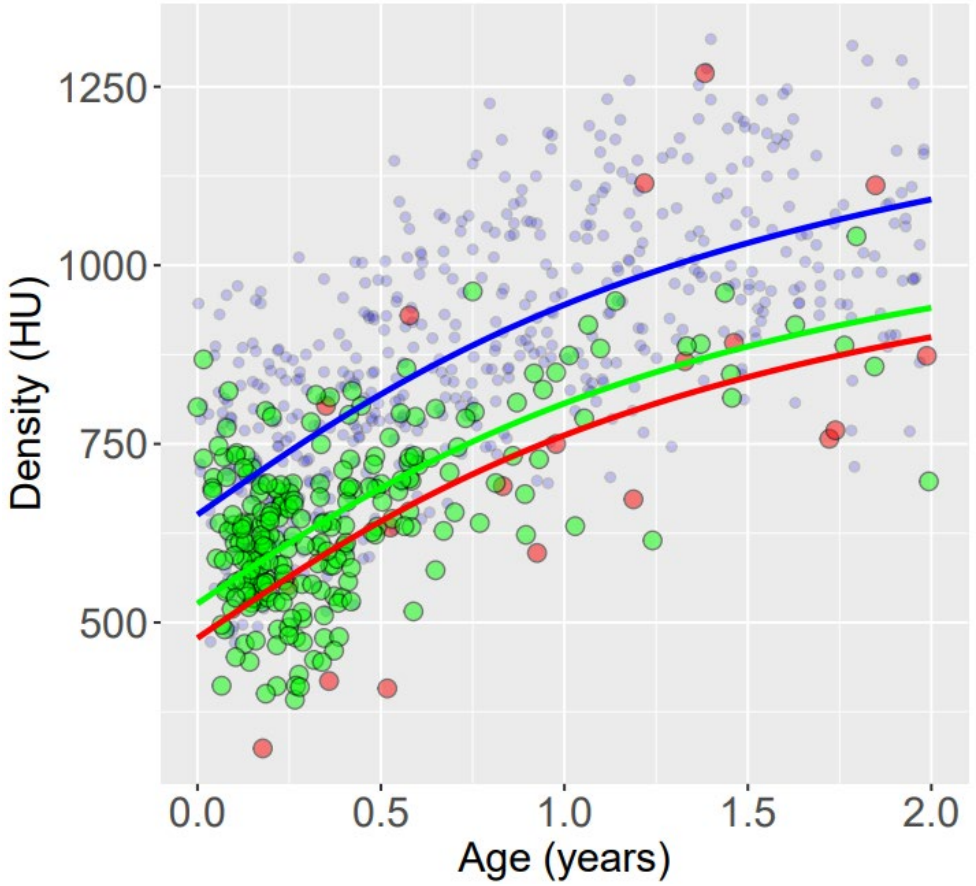


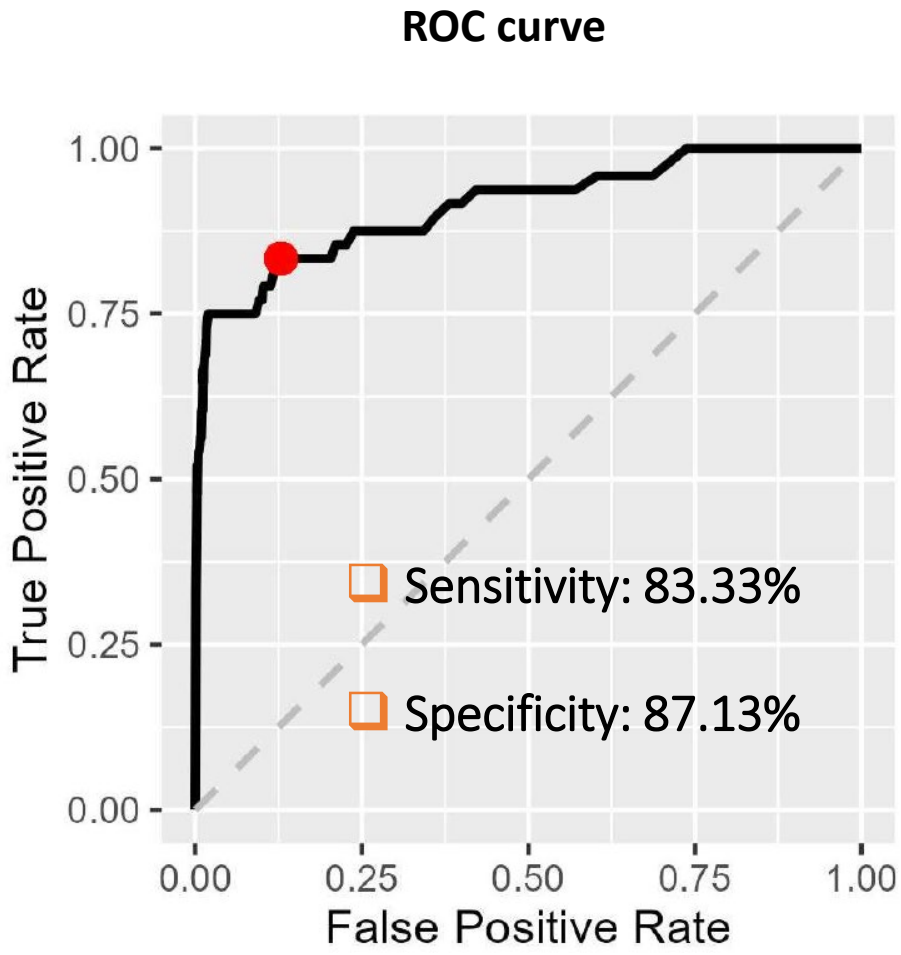




Identification of increased intracranial pressure

- Normative
- Chronic intracranial hypertension
- Non-syndromic sagittal craniosynostosis

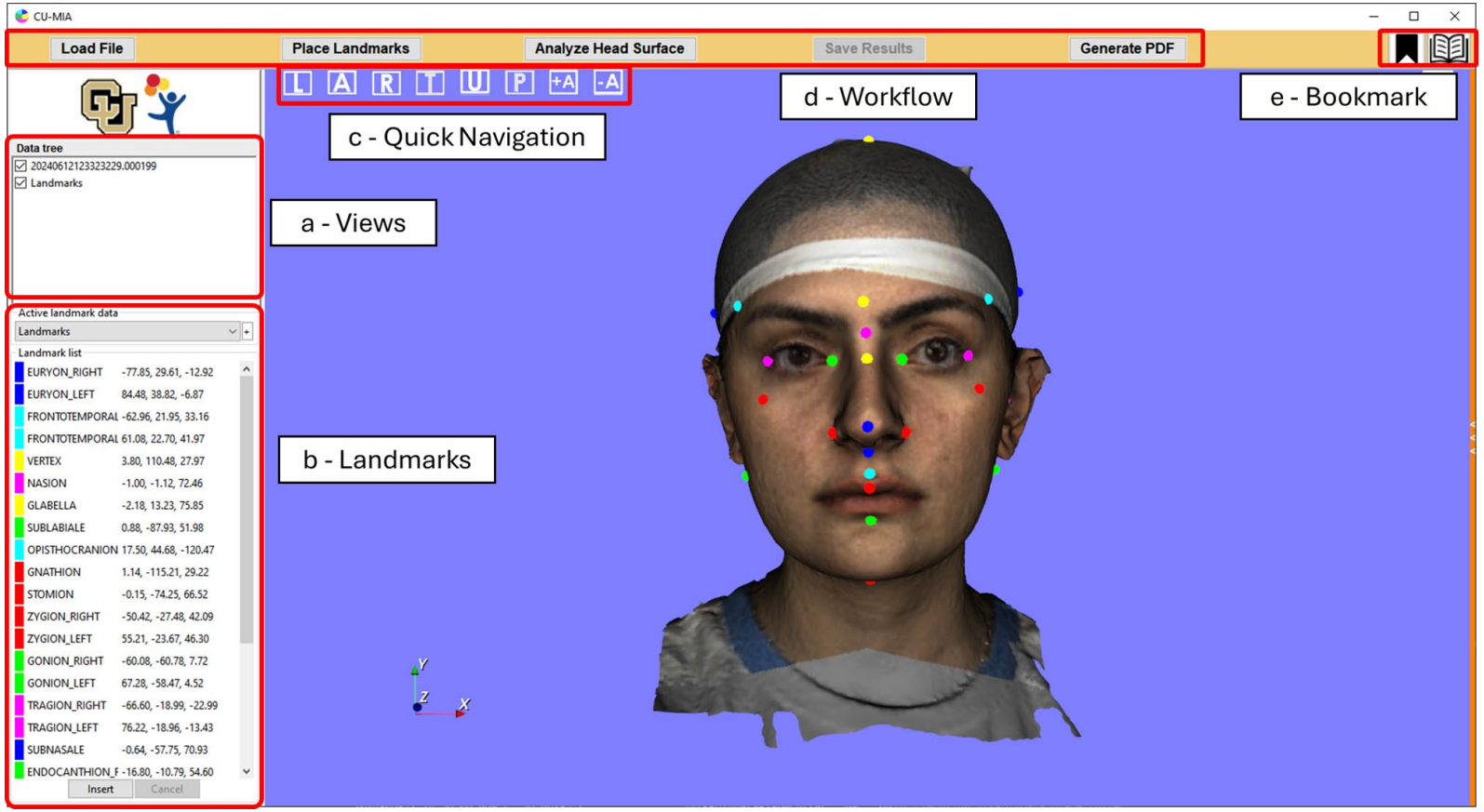




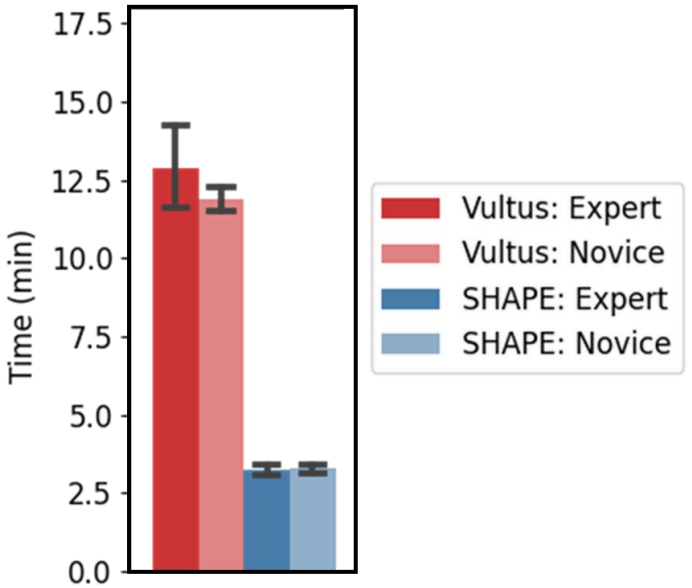
[Liu et al, Cranial bone thickness and density anomalies quantified from CT images can identify chronic increased intracranial pressure, Neurorad, 2024]

Clinical translation

- Optimizing clinical workflows with **SHAPE**



Inter-operator variability (mm)	
Landmark Type	**Vultus (vendor)**
1	3.30 ± 2.56
2	10.68 ± 7.10
3	11.62 ± 11.87
Average	**7.30 ± 7.80**



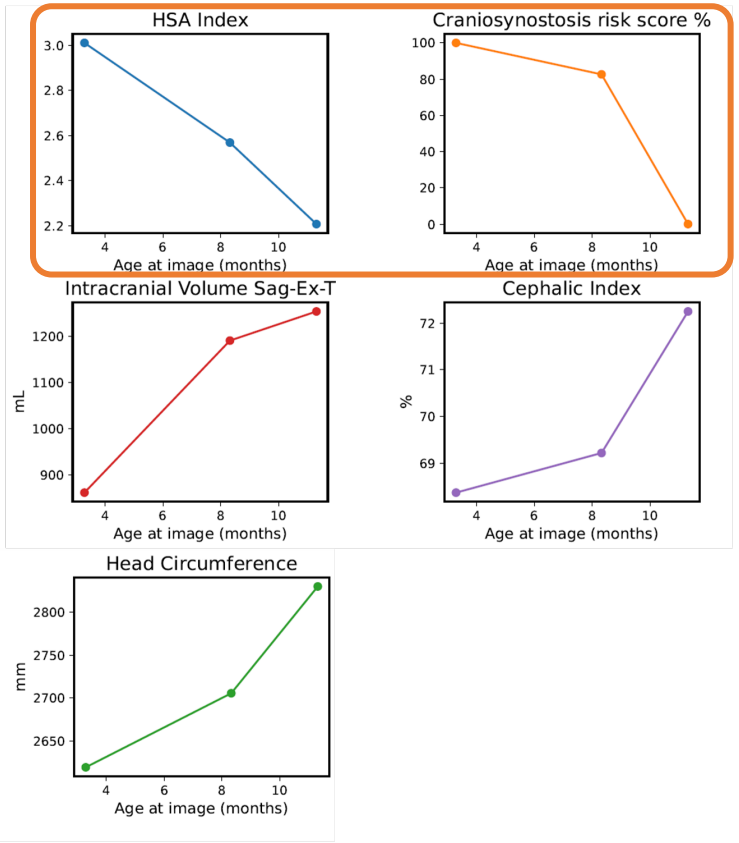
[Görg et al, SHAPE: a visual computing pipeline for interactive landmarking of 3D photograms and patient reporting for assessing craniosynostosis, *Under review*]

Clinical translation

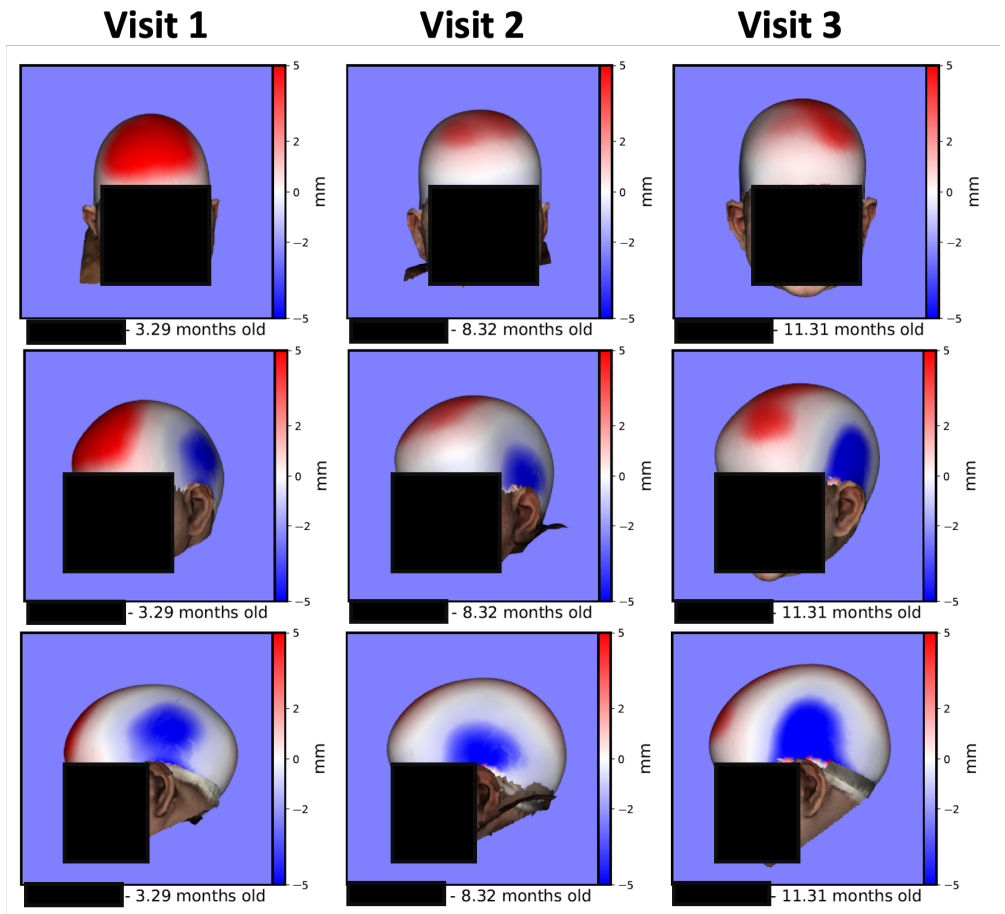
- Automated EHR reports

Craniofacial measurements

Date of original image	[redacted]	[redacted]	[redacted]
Age at image (months)	3.29	8.32	11.31
Biocular Width	69.96	70.98	72.57
Cephalic Index	68.36	69.21	72.25
Cranial Vault Asymmetry Index	1.00	1.02	1.02
Craniosynostosis risk score %	100.00	82.62	0.00
Cutaneous Upper Lip Height	10.26	8.28	9.57
Face Height	71.30	77.84	88.19
Face Width	84.70	94.75	88.53
Forehead Width	91.44	94.69	97.24
Head Circumference	2618.92	2705.33	2829.90
Head Height	151.51	158.59	177.02
Head Length	150.83	157.35	160.47
Head Width	103.12	108.91	115.94
HSA Index	3.01	2.57	2.21
Intercanthal Width	24.72	25.72	26.53
Intracranial Volume Level 2 to 10	689.16	842.09	873.98
Intracranial Volume Sag-Ex-T	861.38	1190.92	1254.10
Lower 1/3 Face Depth LEFT	59.58	52.81	63.01
Lower 1/3 Face Depth RIGHT	57.27	48.98	60.55
Lower 1/3 Face Height	40.63	42.07	54.51
Lower 1/3 Face Height-Mandible	33.80	36.13	45.92
Mandible Width	94.85	77.17	100.88
Middle 1/3 Face Depth LEFT	74.13	80.30	85.29
Middle 1/3 Face Depth RIGHT	73.97	80.43	84.30
Nasal Asymmetry (Alar to Tip)	0.79	1.11	1.14
Nasal Tip Protrusion	10.76	11.24	14.31
Nose Height	24.69	27.47	27.66
Nose Width	23.83	23.20	28.41
Orbital Asymmetry	0.35	0.36	0.37
Upper Face Height	8.27	10.50	7.51
Upper Lip Vermillion Height	5.77	5.12	30.63

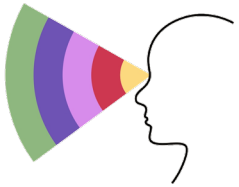


Local malformations



[Görg et al, SHAPE: a visual computing pipeline for interactive landmarking of 3D photograms and patient reporting for assessing craniosynostosis, *Under review*]

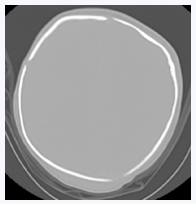
Why data science and AI?

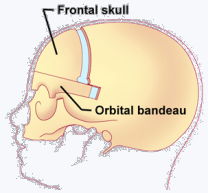


Pre-surgical evaluation

Treatment

Post-surgical evaluation





Pediatric craniofacial biobank

Children's Hospital Colorado

University of Colorado Anschutz Medical Campus

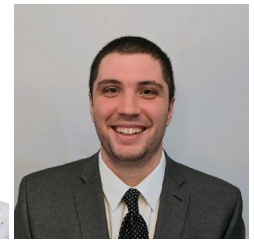
...

Thank you!

antonio.porras@cuanschutz.edu

colorado school of public health



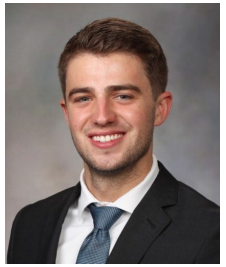
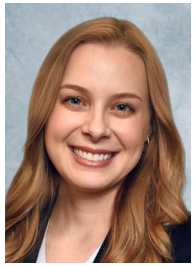




Children's Hospital Colorado







Children's National



Children's Hospital LOS ANGELES

EMORY

NIH National Institute of Dental and Craniofacial Research

R01DE032681 R21DE031824
R01DE030286 R00DE027993
K99DE032681 F31DE033614

NIH *Eunice Kennedy Shriver* National Institute of Child Health and Human Development

R42HD081712

NIH National Center for Advancing Translational Sciences

UM1TR004933

Colorado Clinical and Translational Sciences Institute (CCTSI)
UNIVERSITY OF COLORADO DENVER | ANSCHUTZ MEDICAL CAMPUS

TL1TR2533

Center for Children's Surgery Innovation award