

Introduction

Patients with cleft lip may have abnormal lip movements secondary to altered muscle anatomy and post-operative scarring.

- Traditional 2D and 3D imaging methods capture static expressions but fail to reflect dynamic motion.
- 4D imaging (3D over time) allows real-time visualization of facial movements during speech.
- 4D analysis of lip movement during speech can:
 - Help evaluate functional outcomes
 - Guide further intervention
 - Provide objective, quantifiable measures

Purpose: To analyze dynamic lip movement in children with repaired cleft lip versus controls using 4D stereophotogrammetry and shape analysis.

Shape Analysis Challenge: developing methods that can accurately and efficiently interpret how facial shapes change over time, across specific regions of interest, and between different patient groups, given the massive and complex 4D datasets.

Previous Work analyzed:

- Left to right facial asymmetry at different timepoints during facial expressions (e.g. Smiling)
- Magnitude and displacement of key landmarks across different facial expressions
- Vector analysis, measuring both magnitude and direction of facial movements

This study analyzed:

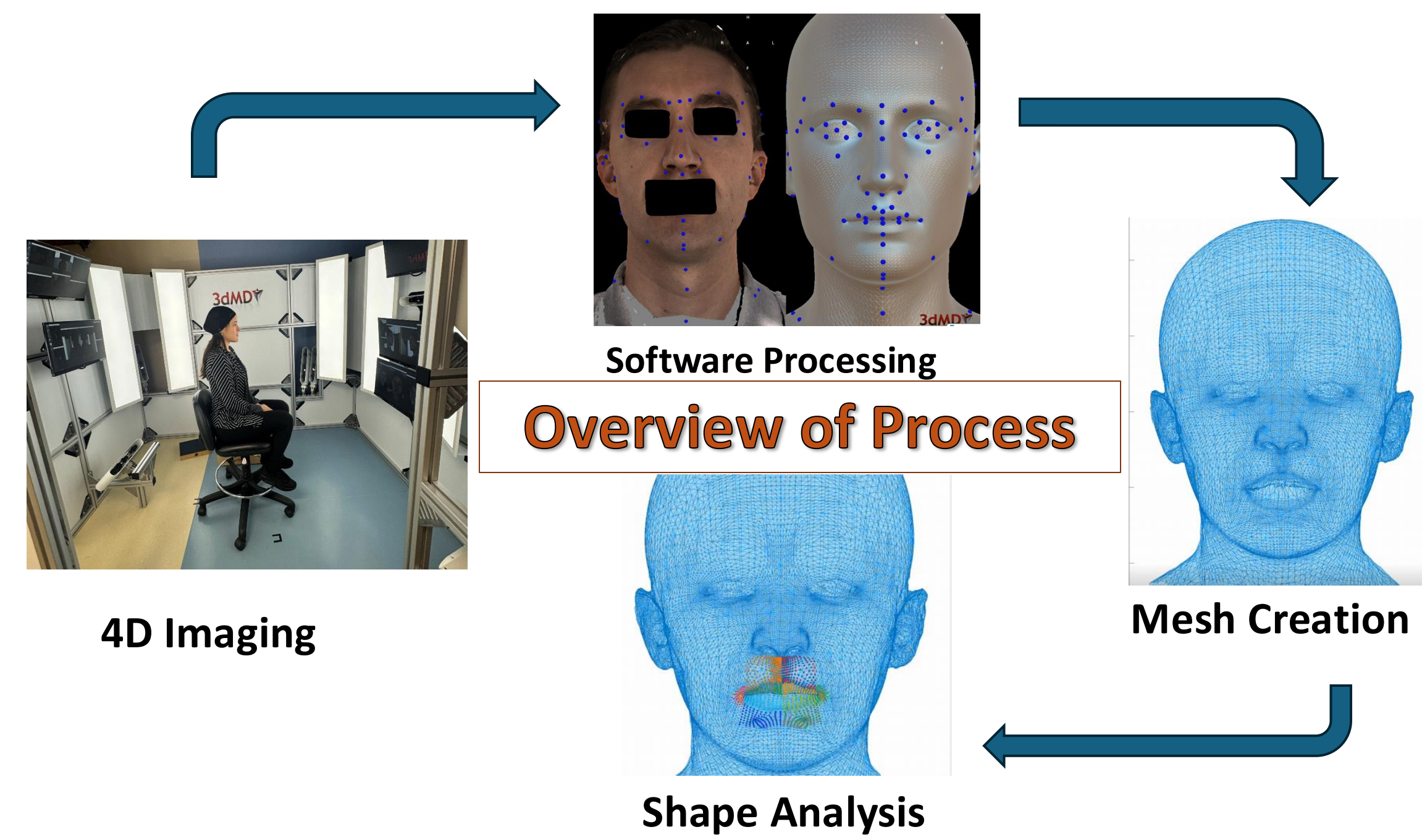
- Procrustes shape analysis on lip and perioral regions during 4 different speech sounds
- Stretch and compression of facial skin during target speech sounds.

Contact Information:

Email: michelle.novoa@utsouthwestern.edu

Methods and Materials

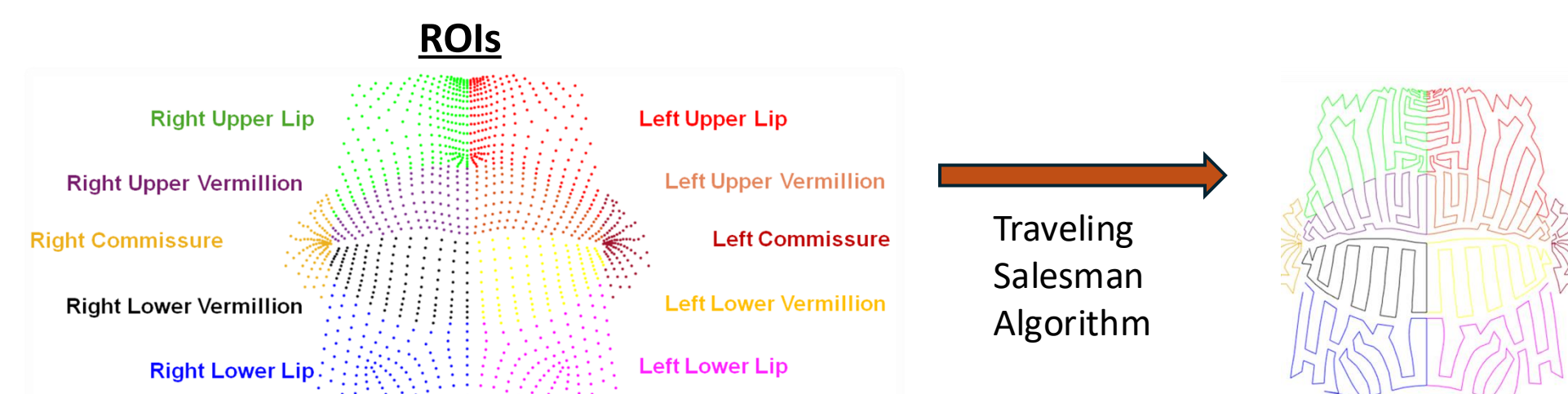
Category	Details	
Age Range	6 – 14 years old (21 in control group, 23 in cleft group)	
2 groups	Patients	Non-syndromic patients with repaired unilateral cleft lip , with or without cleft palate
	Control	Individuals without craniofacial or speech conditions



- 4D imaging captured synchronized video and audio while subjects recited:

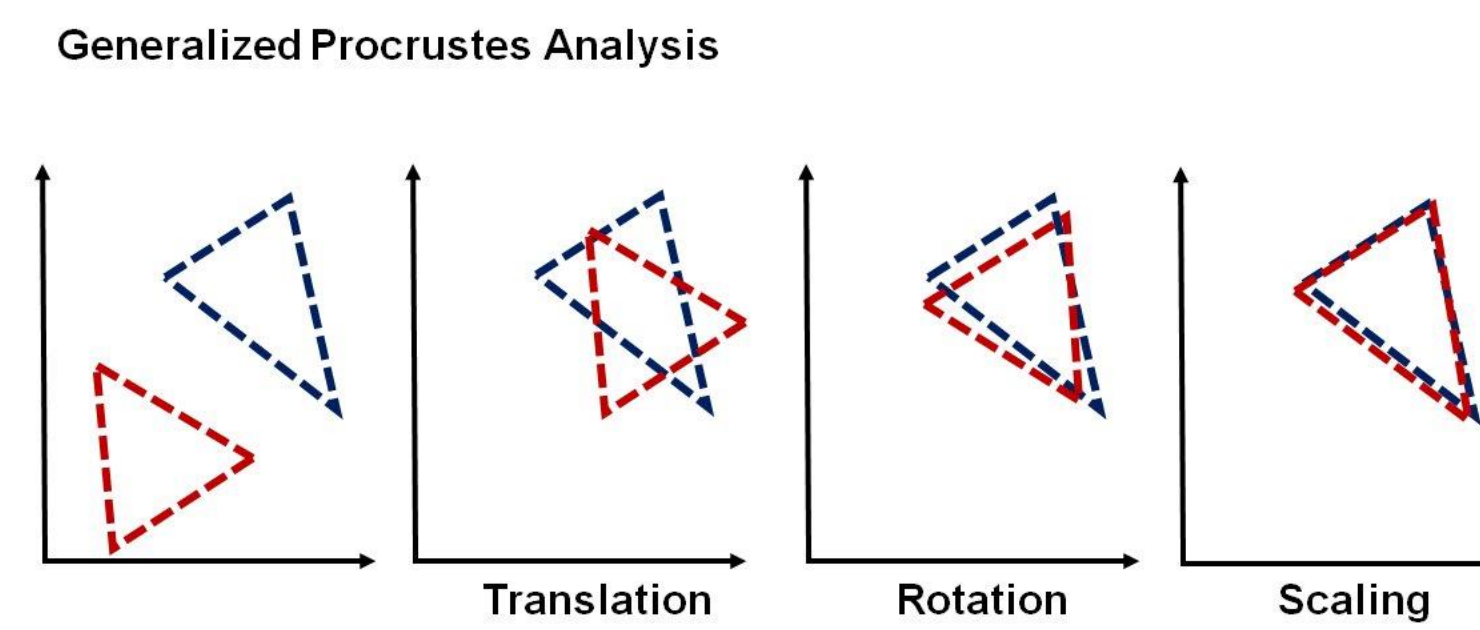
“Joshua Points to Every Brown Feather.”

- Sentence phonemes to increase lip movement included: /p/, /b/, /f/ and /v/
- Processing of 4D imaging via 3dMD tempus software generated participant face masks from a standard mask.
 - Meshes were then aligned
 - Average mesh created for each group for group comparisons
 - Mesh regions of interest (ROIs) were selected for analysis



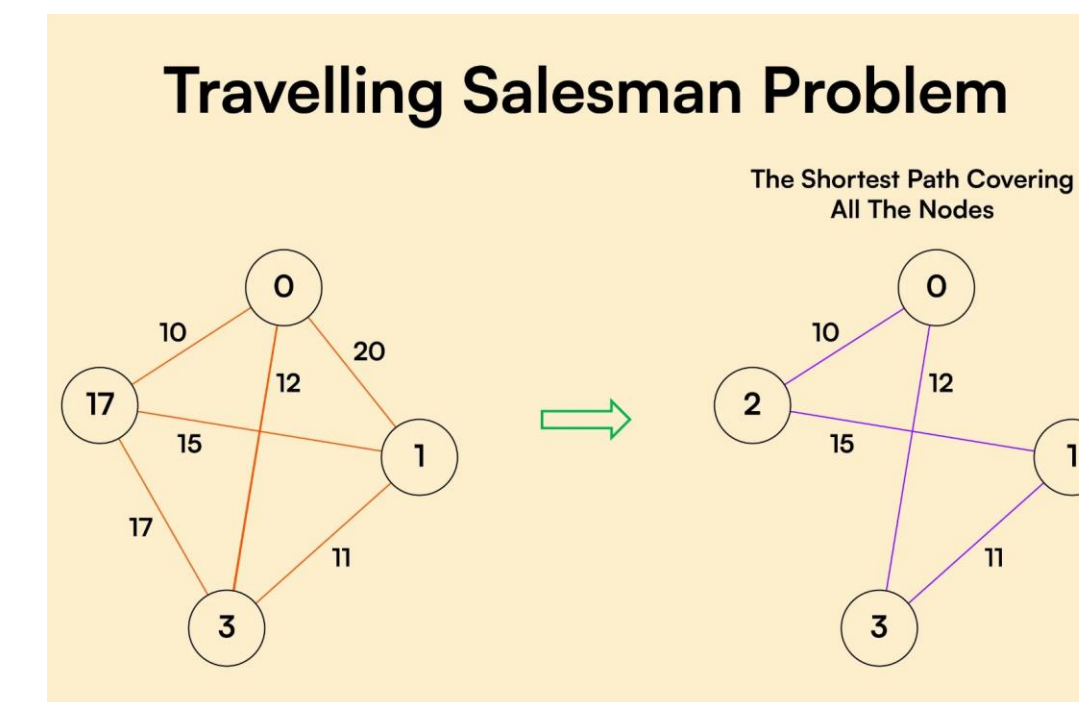
Analysis & Algorithms

- Procrustes:** allows us to compare two shapes in space by aligning them through translation, rotation and scaling to achieve the best possible fit 3 dimensionally.
 - Requires a well-defined shape for analysis

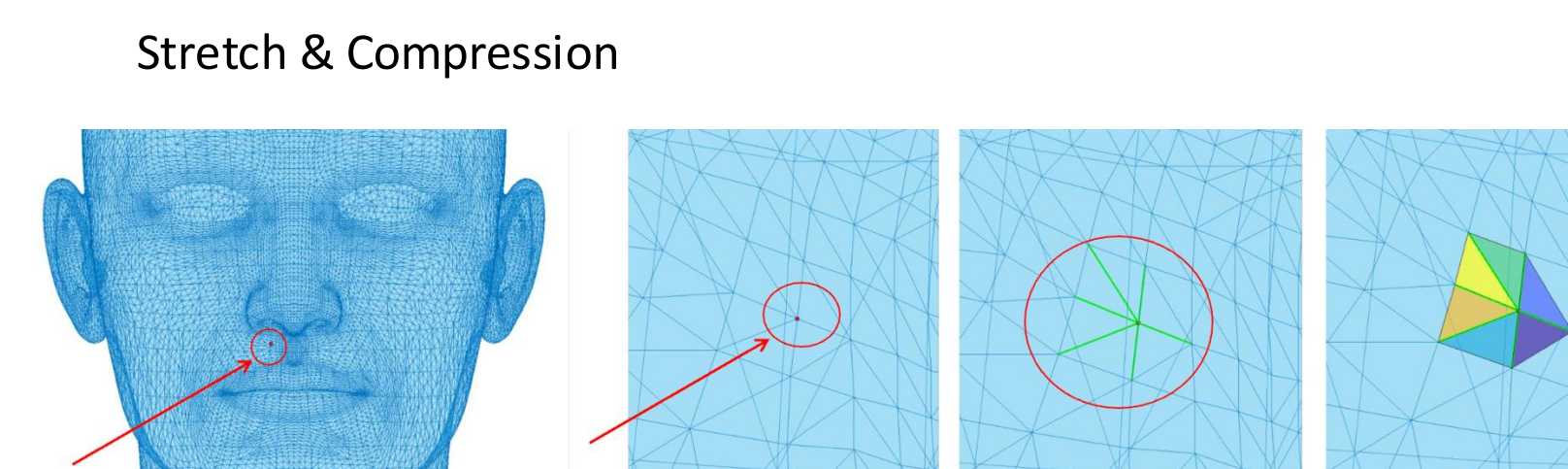


- T-tests:** identified statistically significant differences.

- Traveling Salesman Algorithm:** Connects facial landmarks into closed loops. Used to create shapes for Procrustes Analysis.



- Stretch/Compression:** Tracks change in triangle area on the mesh surface



Results

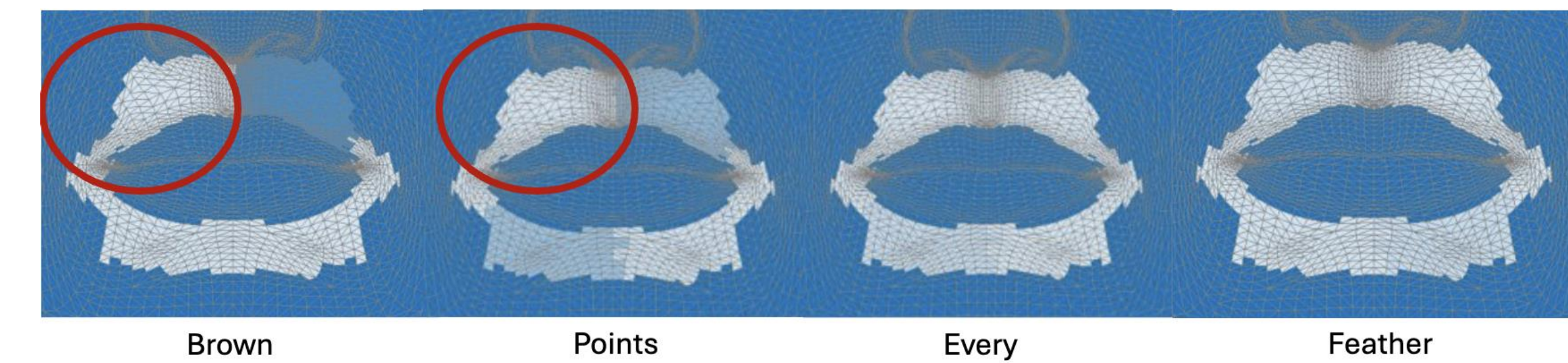
Procrustes:

- P values for T tests between the cleft and control groups for all the ROIs in our 4 speech sounds.

T-test (2-tailed, unpaired) between Controls and Repaired Unilateral Cleft Lip															
Brown ("B" sound)				Every ("V")				Feather ("F" sound)				Points ("oi" sound)			
Upper Lip				Upper Lip				Upper Lip				Upper Lip			
LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
X 0.73	X 0.42	X 0.11	X 0.49	X 0.22	X 0.67	X 0.02	X 0.01	X 0.95	X 0.47	X 0.95	X 0.47	X 0.95	X 0.47	X 0.95	X 0.47
Y 0.92	Y 0.31	Y 0.42	Y 0.37	Y 0.22	Y 0.67	Y 0.22	Y 0.67	Y 0.30	Y 0.18	Y 0.30	Y 0.18	Y 0.30	Y 0.18	Y 0.30	Y 0.18
Z 0.44	Z 0.72	Z 0.80	Z 0.84	Z 0.29	Z 0.84	Z 0.29	Z 0.84	Z 0.34	Z 0.70	Z 0.34	Z 0.70	Z 0.34	Z 0.70	Z 0.34	Z 0.70
Roll (Z) 0.02	Roll (Z) 0.87	Roll (Z) 0.87	Roll (Z) 0.98	Roll (Z) 0.40	Roll (Z) 0.83	Roll (Z) 0.40	Roll (Z) 0.83	Roll (Z) 0.00	Roll (Z) 0.09	Roll (Z) 0.00	Roll (Z) 0.09	Roll (Z) 0.00	Roll (Z) 0.09	Roll (Z) 0.00	Roll (Z) 0.09
Yaw (Y) 0.45	Yaw (Y) 0.36	Yaw (Y) 0.08	Yaw (Y) 0.44	Yaw (Y) 0.05	Yaw (Y) 0.00	Yaw (Y) 0.05	Yaw (Y) 0.00	Yaw (Y) 0.70	Yaw (Y) 0.86	Yaw (Y) 0.70	Yaw (Y) 0.86	Yaw (Y) 0.70	Yaw (Y) 0.86	Yaw (Y) 0.70	Yaw (Y) 0.86
Pitch (X) 0.97	Pitch (X) 0.45	Pitch (X) 0.45	Pitch (X) 0.39	Pitch (X) 0.20	Pitch (X) 0.69	Pitch (X) 0.20	Pitch (X) 0.69	Pitch (X) 0.35	Pitch (X) 0.27	Pitch (X) 0.35	Pitch (X) 0.27	Pitch (X) 0.35	Pitch (X) 0.27	Pitch (X) 0.35	Pitch (X) 0.27
Lower Lip				Lower Lip				Lower Lip				Lower Lip			
LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
X 0.03	X 0.01	X 0.80	X 0.20	X 0.33	X 0.11	X 0.01	X 0.00	X 0.01	X 0.00	X 0.01	X 0.00	X 0.01	X 0.00	X 0.01	X 0.00
Y 0.00	Y 0.04	Y 0.20	Y 0.20	Y 0.05	Y 0.11	Y 0.05	Y 0.11	Y 0.06	Y 0.02	Y 0.06	Y 0.02	Y 0.06	Y 0.02	Y 0.06	Y 0.02
Z 0.01	Z 0.00	Z 0.08	Z 0.03	Z 0.19	Z 0.16	Z 0.19	Z 0.16	Z 0.08	Z 0.01	Z 0.08	Z 0.01	Z 0.08	Z 0.01	Z 0.08	Z 0.01
Roll (Z) 0.01	Roll (Z) 0.20	Roll (Z) 0.25	Roll (Z) 0.16	Roll (Z) 0.09	Roll (Z) 0.24	Roll (Z) 0.09	Roll (Z) 0.24	Roll (Z) 0.46	Roll (Z) 0.01	Roll (Z) 0.46	Roll (Z) 0.01	Roll (Z) 0.46	Roll (Z) 0.01	Roll (Z) 0.46	Roll (Z) 0.01
Yaw (Y) 0.10	Yaw (Y) 0.05	Yaw (Y) 0.97	Yaw (Y) 0.45	Yaw (Y) 0.41	Yaw (Y) 0.29	Yaw (Y) 0.41	Yaw (Y) 0.29	Yaw (Y) 0.01	Yaw (Y) 0.01	Yaw (Y) 0.01	Yaw (Y) 0.01	Yaw (Y) 0.01	Yaw (Y) 0.01	Yaw (Y) 0.01	Yaw (Y) 0.01
Pitch (X) 0.05	Pitch (X) 0.18	Pitch (X) 0.85	Pitch (X) 0.76	Pitch (X) 0.37	Pitch (X) 0.54	Pitch (X) 0.37	Pitch (X) 0.54	Pitch (X) 0.04	Pitch (X) 0.02	Pitch (X) 0.04	Pitch (X) 0.02	Pitch (X) 0.04	Pitch (X) 0.02	Pitch (X) 0.04	Pitch (X) 0.02
Upper Vermillion				Upper Vermillion				Upper Vermillion				Upper Vermillion			
LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
X 0.00	X 0.00	X 0.66	X 0.15	X 0.75	X 0.84	X 0.00	X 0.00	X 0.00	X 0.00	X 0.00	X 0.00	X 0.00	X 0.00	X 0.00	X 0.00
Y 0.08	Y 0.15	Y 0.37	Y 0.06	Y 0.75	Y 0.79	Y 0.08	Y 0.15	Y 0.08	Y 0.15	Y 0.08	Y 0.15	Y 0.08	Y 0.15	Y 0.08	Y 0.15
Z 0.85	Z 0.59	Z 0.37	Z 0.60	Z 0.49	Z 0.17	Z 0.49	Z 0.17	Z 0.07	Z 0.63	Z 0.07	Z 0.63	Z 0.07	Z 0.63	Z 0.07	Z 0.63
Roll (Z) 0.01	Roll (Z) 0.00	Roll (Z) 0.29	Roll (Z) 0.06	Roll (Z) 0.38	Roll (Z) 0.10	Roll (Z) 0.38	Roll (Z) 0.10	Roll (Z) 0.11	Roll (Z) 0.01	Roll (Z) 0.11	Roll (Z) 0.01	Roll (Z) 0.11	Roll (Z) 0.01	Roll (Z) 0.11	Roll (Z) 0.01
Yaw (Y) 0.01	Yaw (Y) 0.00	Yaw (Y) 0.49	Yaw (Y) 0.10	Yaw (Y) 0.01	Yaw (Y) 0.63	Yaw (Y) 0.01	Yaw (Y) 0.63	Yaw (Y) 0.00	Yaw (Y) 0.01	Yaw (Y) 0.00	Yaw (Y) 0.01	Yaw (Y) 0.00	Yaw (Y) 0.01	Yaw (Y) 0.00	Yaw (Y) 0.01
Pitch (X) 0.02	Pitch (X) 0.02	Pitch (X) 0.29	Pitch (X) 0.05	Pitch (X) 0.59	Pitch (X) 0.99	Pitch (X) 0.59	Pitch (X) 0.99	Pitch (X) 0.24	Pitch (X) 0.45	Pitch (X) 0.24	Pitch (X) 0.45	Pitch (X) 0.24	Pitch (X) 0.45	Pitch (X) 0.24	Pitch (X) 0.45
Lower Vermillion				Lower Vermillion				Lower Vermillion				Lower Vermillion			
LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
X 0.69	X 0.44	X 0.53	X 0.61	X 0.75	X 0.40	X 0.69	X 0.44	X 0.12	X 0.13	X 0.12	X 0.13	X 0.12	X 0.13	X 0.12	X 0.13
Y 0.54	Y 0.59	Y 0.98	Y 0.16	Y 0.37	Y 0.25	Y 0.54	Y 0.59	Y 0.08	Y 0.01	Y 0.08	Y 0.01	Y 0.08	Y 0.01	Y 0.08	Y 0.01
Z 0.05	Z 0.01	Z 0.31	Z 0.59	Z 0.23	Z 0.14	Z 0.23	Z 0.14	Z 0.05	Z 0.01	Z 0.05	Z 0.01	Z 0.05	Z 0.01	Z 0.05	Z 0.01
Roll (Z) 0.37	Roll (Z) 0.77	Roll (Z) 0.74	Roll (Z) 0.89	Roll (Z) 0.10	Roll (Z) 0.89	Roll (Z) 0.10	Roll (Z) 0.89	Roll (Z) 0.76	Roll (Z) 0.05	Roll (Z) 0.76	Roll (Z) 0.05	Roll (Z) 0.76	Roll (Z) 0.05	Roll (Z) 0.76	Roll (Z) 0.05
Yaw (Y) 0.81	Yaw (Y) 0.77	Yaw (Y) 0.55	Yaw (Y) 0.60	Yaw (Y) 0.45	Yaw (Y) 0.13	Yaw (Y) 0.45	Yaw (Y) 0.13	Yaw (Y) 0.44	Yaw (Y) 0.06	Yaw (Y) 0.44	Yaw (Y) 0.06	Yaw (Y) 0.44	Yaw (Y) 0.06	Yaw (Y) 0.44	Yaw (Y) 0.06
Pitch (X) 0.33	Pitch (X) 0.37	Pitch (X) 0.53	Pitch (X) 0.05	Pitch (X) 0.94	Pitch (X) 0.57	Pitch (X) 0.94	Pitch (X) 0.57	Pitch (X) 0.08	Pitch (X) 0.02	Pitch (X) 0.08	Pitch (X) 0.02	Pitch (X) 0.08	Pitch (X) 0.02	Pitch (X) 0.08	Pitch (X) 0.02
Commissure				Commissure				Commissure				Commissure			
LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
X 0.84	X 0.39	X 0.56	X 0.03	X 0.56	X 0.31	X 0.84	X 0.39	X 0.00	X 0.03	X 0.00	X 0.03	X 0.00	X 0.03	X 0.00	X 0.03
Y 0.46	Y 0.34	Y 0.99	Y 0.61	Y 0.46	Y 0.44	Y 0.46	Y 0.34	Y 0.05	Y 0.01	Y 0.05	Y 0.01	Y 0.05	Y 0.01	Y 0.05	Y 0.01
Z 0.00	Z 0.00	Z 0.05	Z 0.11	Z 0.00	Z 0.01	Z 0.00	Z 0.01	Z 0.00	Z 0.00	Z 0.00	Z 0.00	Z 0.00	Z 0.00	Z 0.00	Z 0.00
Roll (Z) 0.12	Roll (Z) 0.07	Roll (Z) 0.79	Roll (Z) 0.98	Roll (Z) 0.51	Roll (Z) 0.17	Roll (Z) 0.12	Roll (Z) 0.07	Roll (Z) 0.00	Roll (Z) 0.00	Roll (Z) 0.00	Roll (Z) 0.00	Roll (Z) 0.00	Roll (Z) 0.00	Roll (Z) 0.00	Roll (Z) 0.00
Yaw (Y) 0.45	Yaw (Y) 0.92	Yaw (Y) 0.99	Yaw (Y) 0.11	Yaw (Y) 0.06	Yaw (Y) 0.69	Yaw (Y) 0.45	Yaw (Y) 0.92	Yaw (Y) 0.00	Yaw (Y) 0.00	Yaw (Y) 0.00	Yaw (Y) 0.00	Yaw (Y) 0.00	Yaw (Y) 0.00	Yaw (Y) 0.00	Yaw (Y) 0.00
Pitch (X) 0.68	Pitch (X) 0.69	Pitch (X) 0.71	Pitch (X) 0.44	Pitch (X) 0.35	Pitch (X) 0.21	Pitch (X) 0.68	Pitch (X) 0.69	Pitch (X) 0.27	Pitch (X) 0.13	Pitch (X) 0.27	Pitch (X) 0.13	Pitch (X) 0.27	Pitch (X) 0.13	Pitch (X) 0.27	Pitch (X) 0.13

Stretch/Compression:

- Non-cleft upper lip showed greater movement—possible compensatory mechanism
- Statistically significant stretch patterns varied by sound and region



Conclusions

- 4D imaging of facial expressions reveals persistent motion differences between control and cleft lip patients, even after repair.
- Asymmetry is greater and more uneven in cleft patients, especially during dynamic speech, emphasizing the need for dynamic functional assessments in post-surgical evaluation

Acknowledgements: Analytical Imaging & Modeling Center