

**4pSC3**

# **Muscular hydrostat mechanism for lip protrusion in speech**

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# Introduction

The lips are speech articulators with several communication functions:

- producing labial sounds
- conveying facial expression
- aiding perceptual understanding of speech visually

Despite their importance, the mechanisms underlying labial gestures, among them labial protrusion, are still unknown.

It is difficult to unveil control mechanisms of the lips because:

- lips are muscular-hydrostatics
- muscles are interdigitated (Blair C., 1986)
- individual anatomic variation is great

Studies of muscle activity shows:

- mentalis and orbicularis oris muscles are involved in protrusion, but it is not clear how they interact (Blair C., 1986; Folkins J.W., 1978; Goffman L., 1994; Honda K., 1995)
- peripheral and marginal fibers of orbicularis oris muscle are differentially activated in rounding vs. protruding (Honda K., 1995)

In this paper we propose to verify quantitatively and qualitatively the mechanism of lip protrusion.

# Methods

## *Subject*

- One male Japanese native speaker participated in 3 sessions of MRI: two with high-resolution static MRI (hr-MRI) and one with tagged-cine MRI (t-MRI).

## *High-resolution static MRI (hr-MRI)*

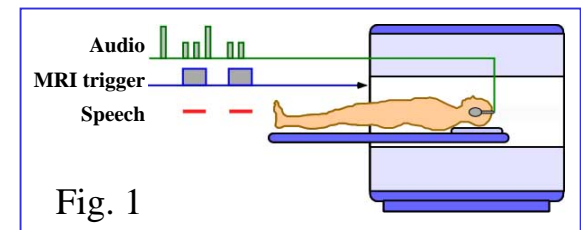
- Shimadzu-Marconi 1.5T MRI from ATR Brain Imaging Center, Japan
- Surface coil (FOV=96mm; 0.19mm resolution) and temporo-mandibular joint coil (FOV=64mm; 0.125mm resolution)
- FSE sequence (TE=16ms, TR=600ms)
- *42 sagittal slices of 2mm thickness, 512x512 pixels*
- *Task: static position at rest position, /i/ and /u/*

## *Analysis of hr-MRI data*

- hand tracing of structures (Photoshop), (Matlab) interpolation (ImageJ and MPR), 3D graphics (Mimics and Rhinocerus), volumetric measurements (Matlab). <sup>3</sup>

# ***Tagged-cine MRI (t-MRI)***

- Marconi 1.5T MRI from the Department of Radiology of the University of Maryland Hospital, USA
- Two TMJ coils in parallel (FOV = 200mm; resolution=1.56mm )
- TR=1037ms and TE=2.2ms for sagittal and TE=1.85ms for coronal and axial
  - ***Sagittal: 12 time-frames in 666ms, 10 slices (5mm)***
  - ***Coronal: 14 time-frames in 666ms, 13 slices (5mm - 2mm gap)***
  - ***Axial: 14 time-frames in 666ms, 11 slices (5mm - 2mm gap)***
- ***Task: Motion from /i/ to /u/***
- Synchronized sampling method (Masaki, 1999) Fig.1
- One set of tagged (tagging space = 5mm) and one set of non-tagged images



## ***Analysis of t-MRI***

- Magnitude C-Spamm – MICSR (NessAliver and Prince, 2003)
- Harmonic Phase (HARP) for tracking tissue point motions over time, calculating principal and Lagrangian strains

# High-Resolution MRI (hr-MRI)

*Anatomical landmarks and Geometric deformation  
(rest, /i/ and /u/)*

# hr-MRI: Enable Excellent Visualization of Inner Structures

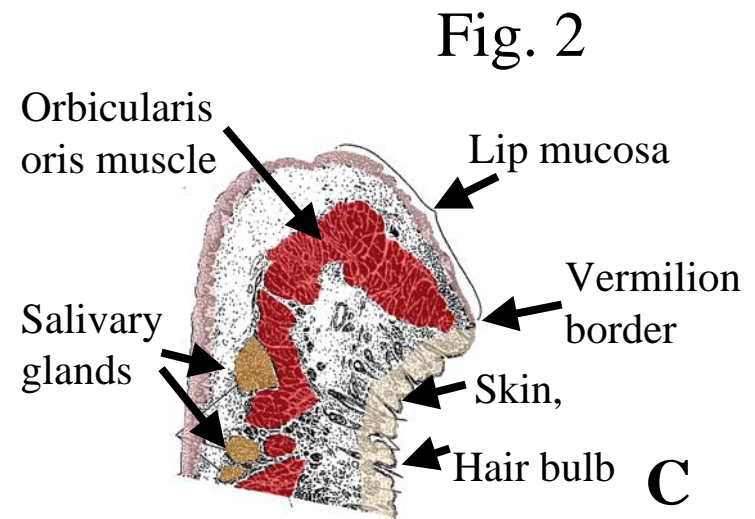
Such as:

- Vermilion border is visible
- Orbicularis oris muscle is hook-shaped
- The hook is seen at the vermilion border



(A) hr-MRI during rest  
(0.125mm resolution)

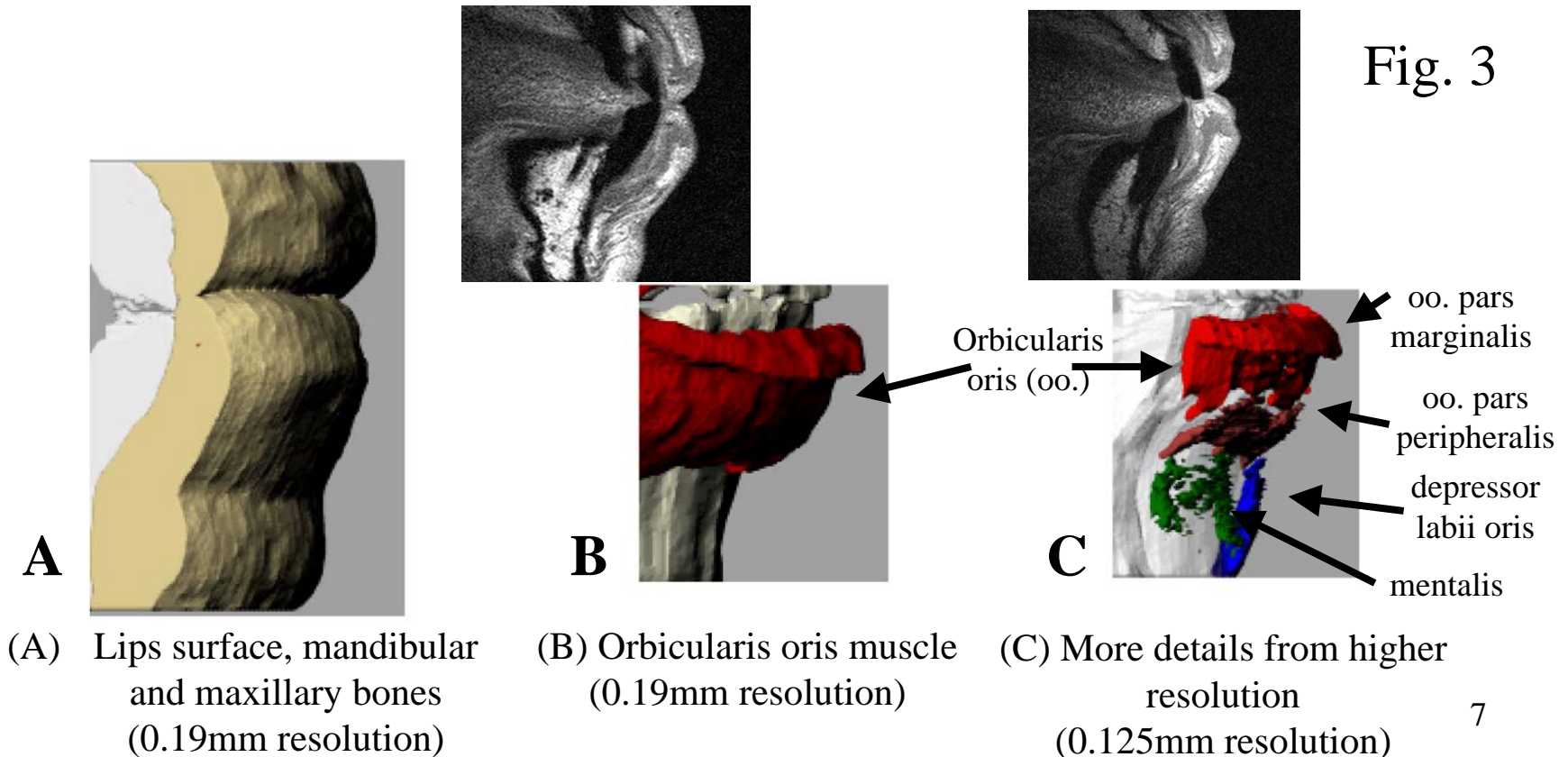
(B) Traced and colored  
version of (A)



(C) Histological slice from  
lower lip (Yoro, 1993)

# hr-MRI: Allows Detailed 3D Reconstruction of Muscles

- Bones, muscle, mucosa and skin are traced and a 3D structure is built.
- Details such as the sparse distribution of pars peripheralis, mentalis and depressor labii oris muscles are extracted.
- 3D reconstruction are made.



# Resulting in 3D reconstruction

Details of lip are visible:

- orbicularis oris muscle eversion
- modiolus medianization
- vermilion border
- protrusion.

rest

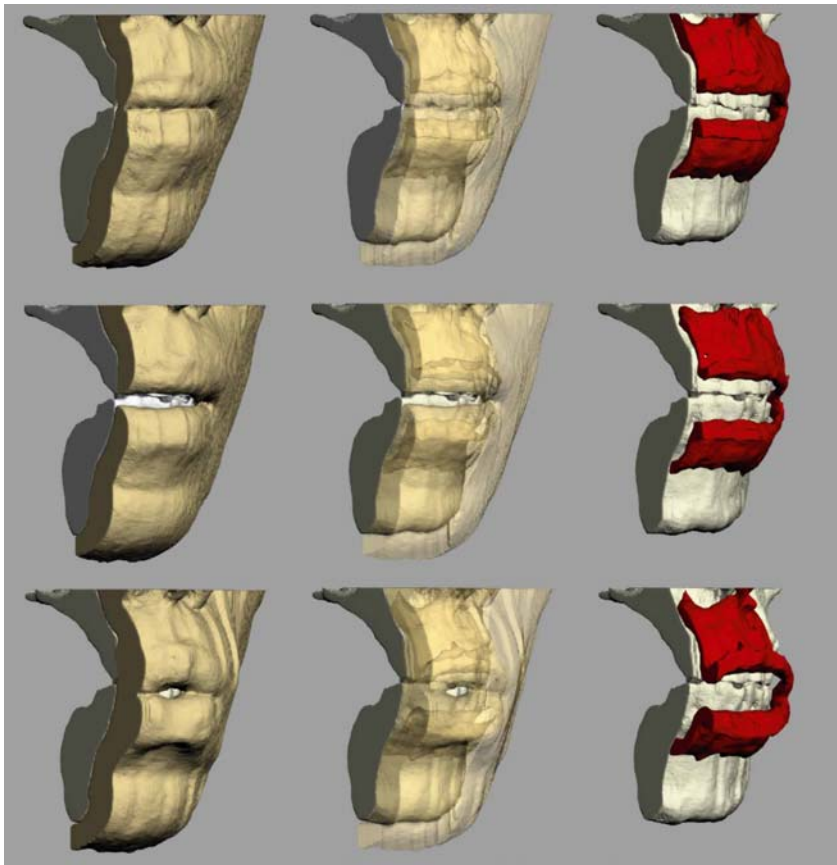
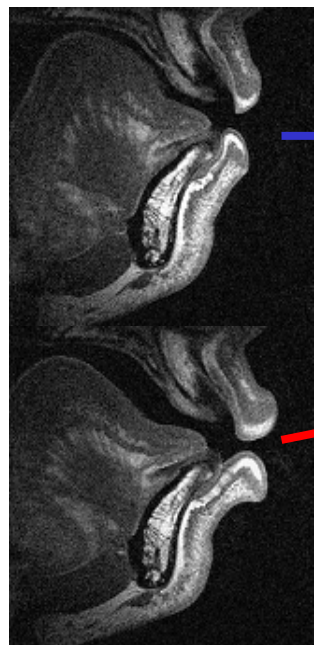
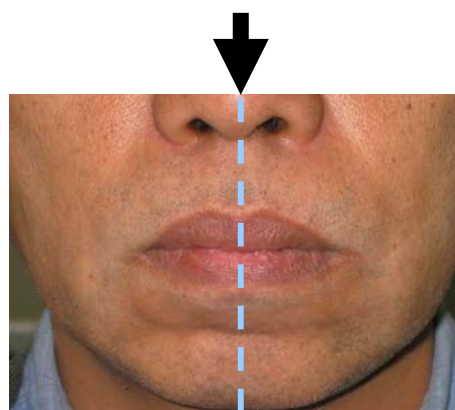


Fig. 4

Transparency levels are increased left-to-right to show the relationship of the structures.

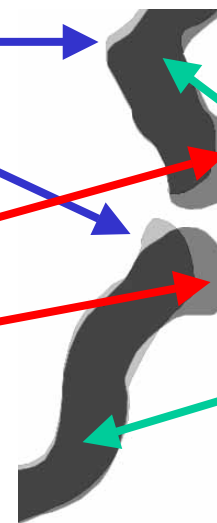
# hr-MRI: Volume Distribution Creates Labial Deformation



**/i/**

**/u/**

Fig. 5



Overlap of  
/i/ and /u/

Midsagittal slice during /i/ and /u/. Tracing of the labial contours are shown.

# Lateral and Medial Volume Change Between Rest and Vowels

- Right upper and lower lips were divided into lateral and medial quadrants and volume calculated.
- Labial boundaries are: line from columella and nasalabial sulcus (a-b), modiolus (c), line from columella to the bottom of face (d) and a straight line from modiolus to the bottom of face.
- Note that for each task these landmarks change themselves, volumes are shown in cm<sup>3</sup> with percents in parenthesis in table 1.

Table 1. Volumetric measurement of lips

task \ quadrant	rest		vowel /i/		vowel /u/	
	lateral	medial	lateral	medial	lateral	medial
upper lip	2.00 (7.1)	5.69 (20.2)	1.72 (6.3)	5.47 (20.1)	1.82 (6.5)	6.49 (23.0)
lower lip	9.00 (31.9)	11.51 (40.8)	8.73 (32.1)	11.27 (41.4)	6.26 (22.2)	13.64 (48.3)

volume values are given in cm<sup>3</sup>

( ) percentage in relation to total volume for each task

Increased in relation  
to rest and /i/

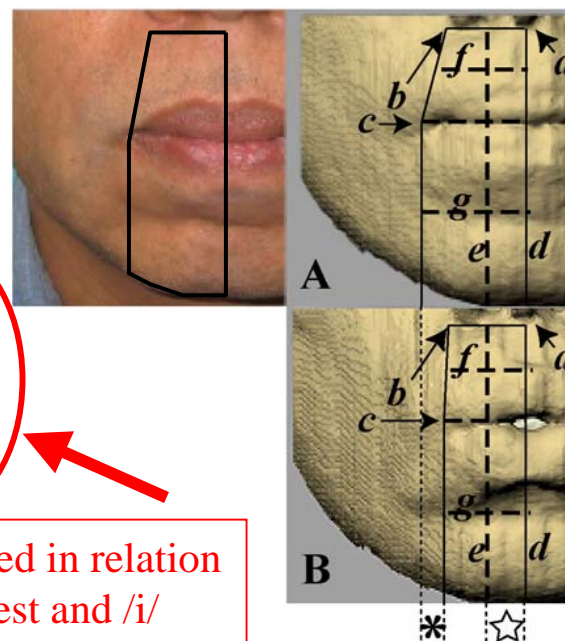


Fig. 6

# Lateral and Medial Volume Change Between Rest and Vowels

Medial quadrant of the right upper and lower lips were divided into three layers:

- The muscular layer is the orbicularis oris muscle.
- The inner layer is mainly dermis and hypodermis (determined from the muscular layer to the labial mucosa).
- The outer layer is interdigitated muscles, dermis and hypodermis (determined from the muscular layer to the skin).

Volume distribution was calculated in relation to the lips in rest position.

Table 2. Volumetric changes in medial quadrant

		<i>task</i>		
<i>layer</i>		rest	vowel /i/	vowel /u/
upper lip	outer	2.12 (100.0)	1.95 (92.0)	2.10 (99.0)
	muscular	1.89 (100.0)	1.81 (95.8)	2.28 (120.7)
	inner	1.68 (100.0)	1.71 (101.9)	2.12 (126.0)
lower lip	outer	8.22 (100.0)	8.07 (98.2)	8.79 (106.9)
	muscular	1.49 (100.0)	1.38 (92.7)	2.23 (149.6)
	inner	1.80 (100.0)	1.82 (100.8)	2.63 (145.8)

volume values are given in cm<sup>3</sup>

( ) percentage in relation to rest task

Decreased in relation  
to rest

Increased in relation  
to rest

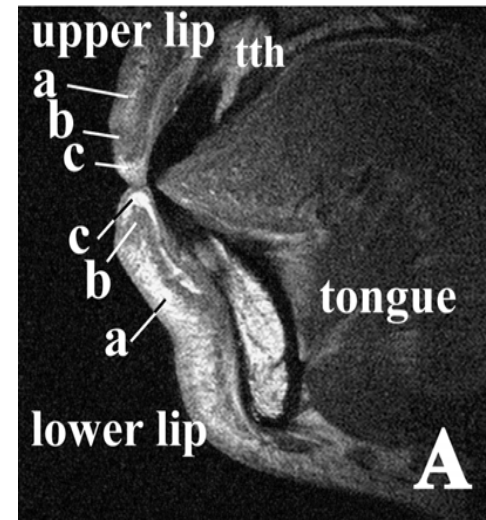


Fig. 7

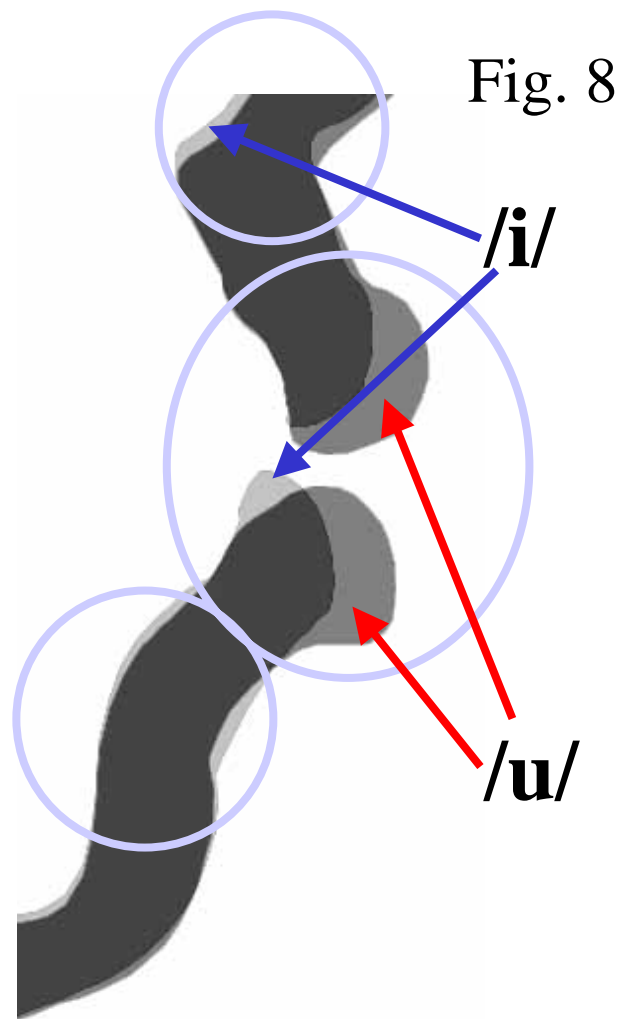
Labial Layers:

a = outer or superficial

b = muscular (orbicularis oris)

c = inner or deep

# Lips have lots of degrees of freedom when seen in detail



This is a good basis for understanding:

- function
- volume preservation

hr-MRI shows:

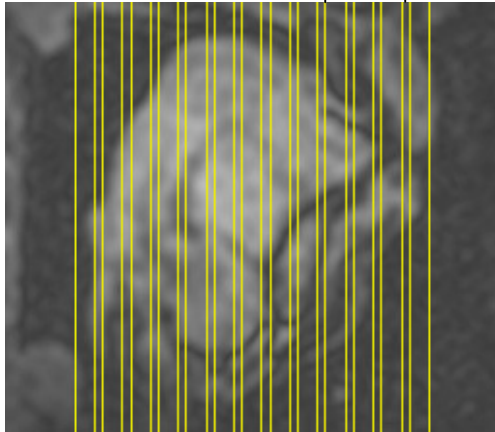
- local deformations
- volume preservation

# Tagged-cine MRI (t-MRI)

*Tissue point tracking,  
principal strains and Lagrangian strains  
(motion from /i/ to /u/)*

# Principal Strains Reflect the Muscles Seen in hr-MRI

CORONAL  
pilot



hr-MRI

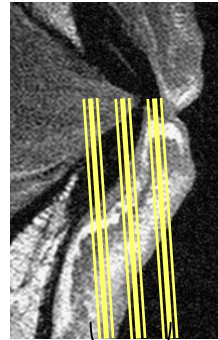
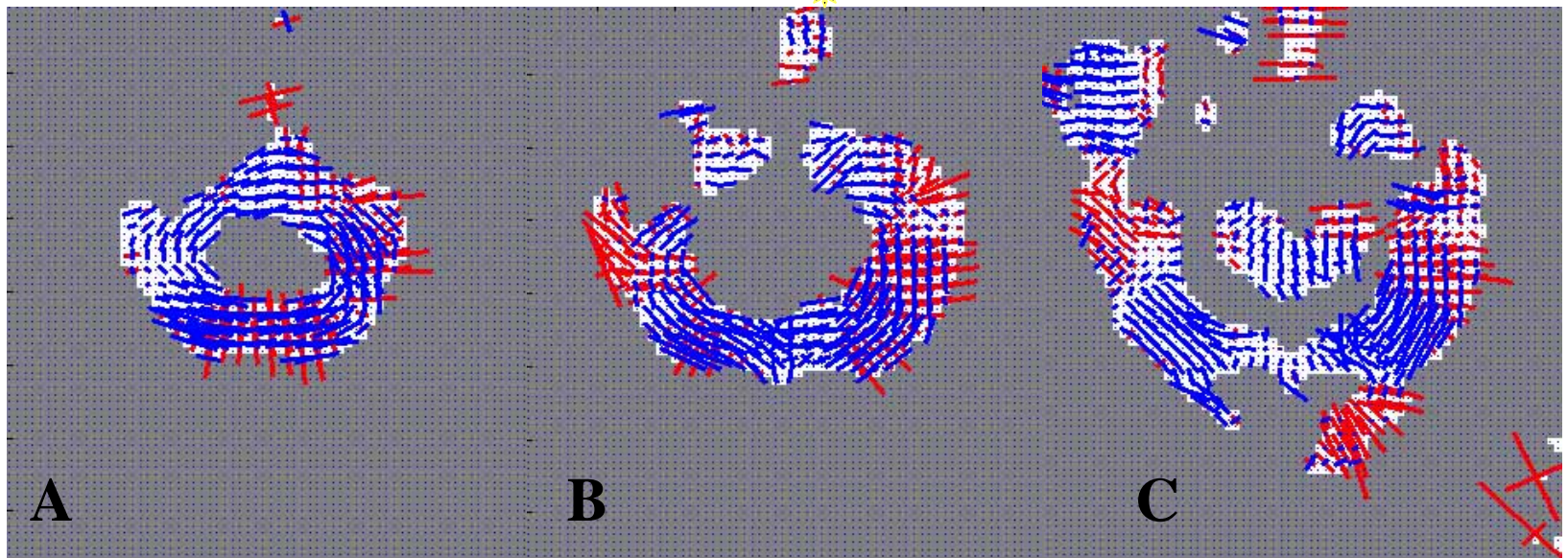


Fig. 9

Principal strains

■ compression

■ expansion



A

B

C

Marginalis compression

Modolus medianization

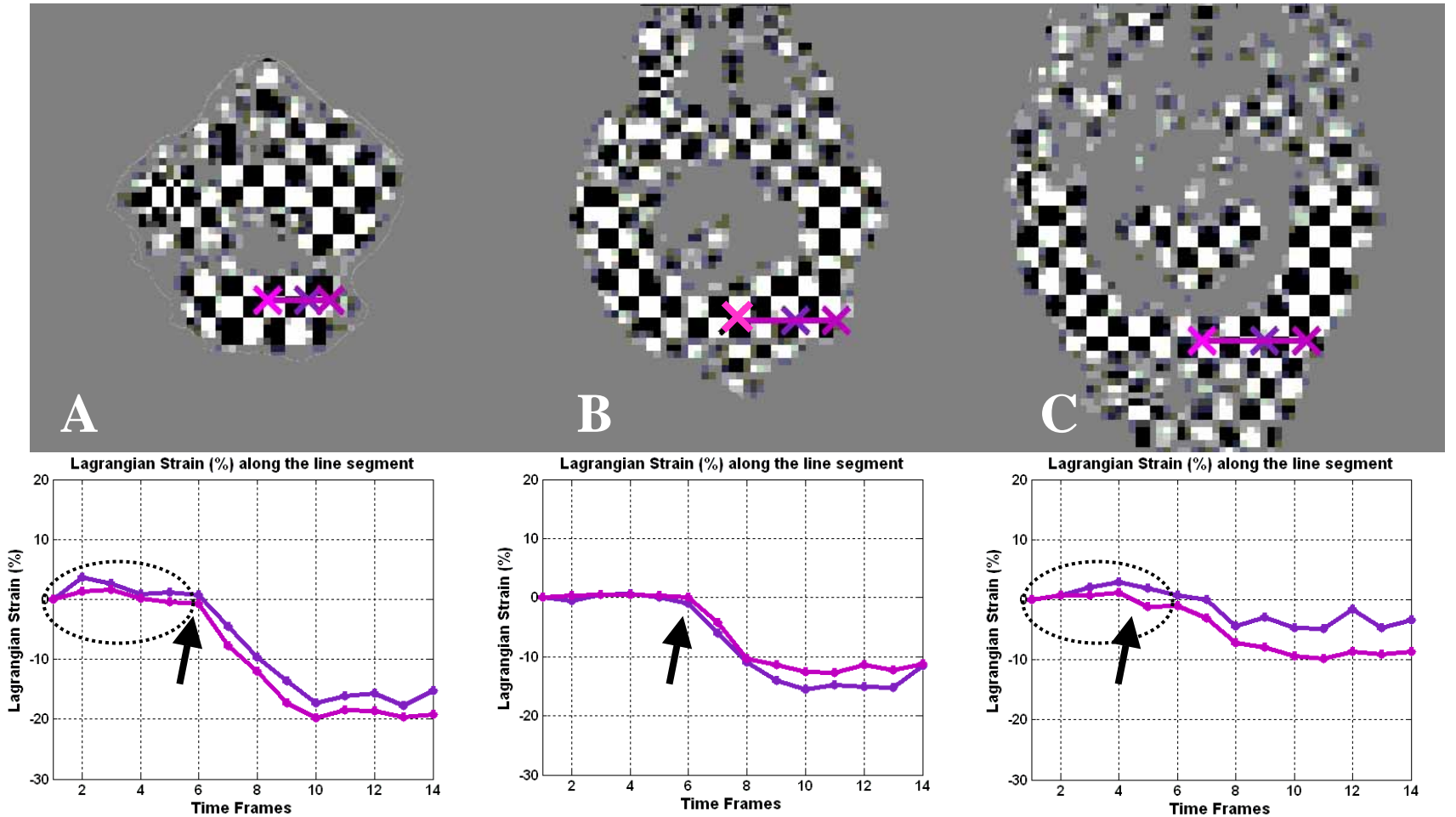
Peripheralsis compression

# Lagrangian Strains Show Compression

CORONAL

## Between Two Points

Fig. 10

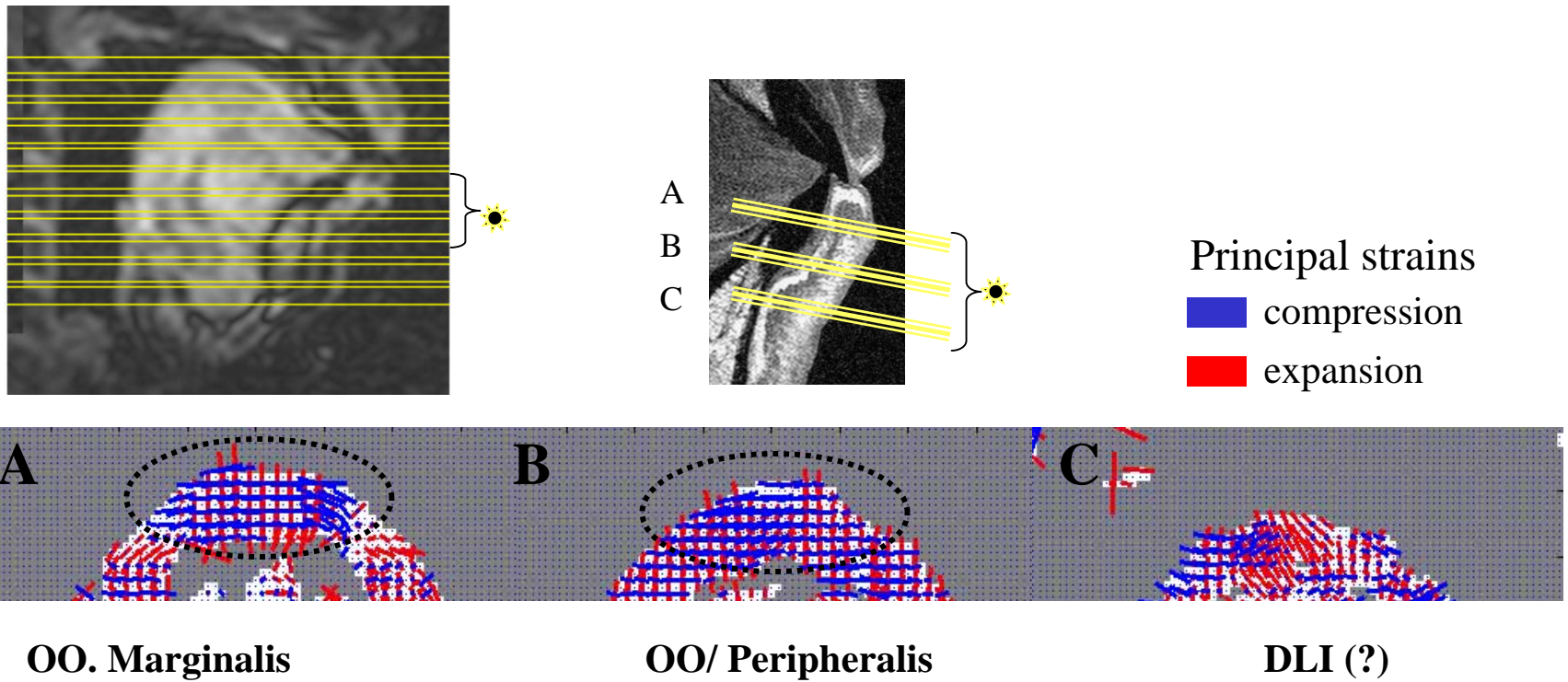


- In Fig. 10A, B slight lip expansion is seen for /i/ (oval), but there is an abrupt compression at frame 6 for /u/, which suggests that OO. muscle contracts at frame 6.
- Fig. 10C shows earlier compression (frame 5)

# Principal Strains Show Expansion and Compression for Protrusion

AXIAL

Fig. 11



# AXIAL Lagrangian Strains Show Initial Exact Timing for /u/ Onset

Fig. 12

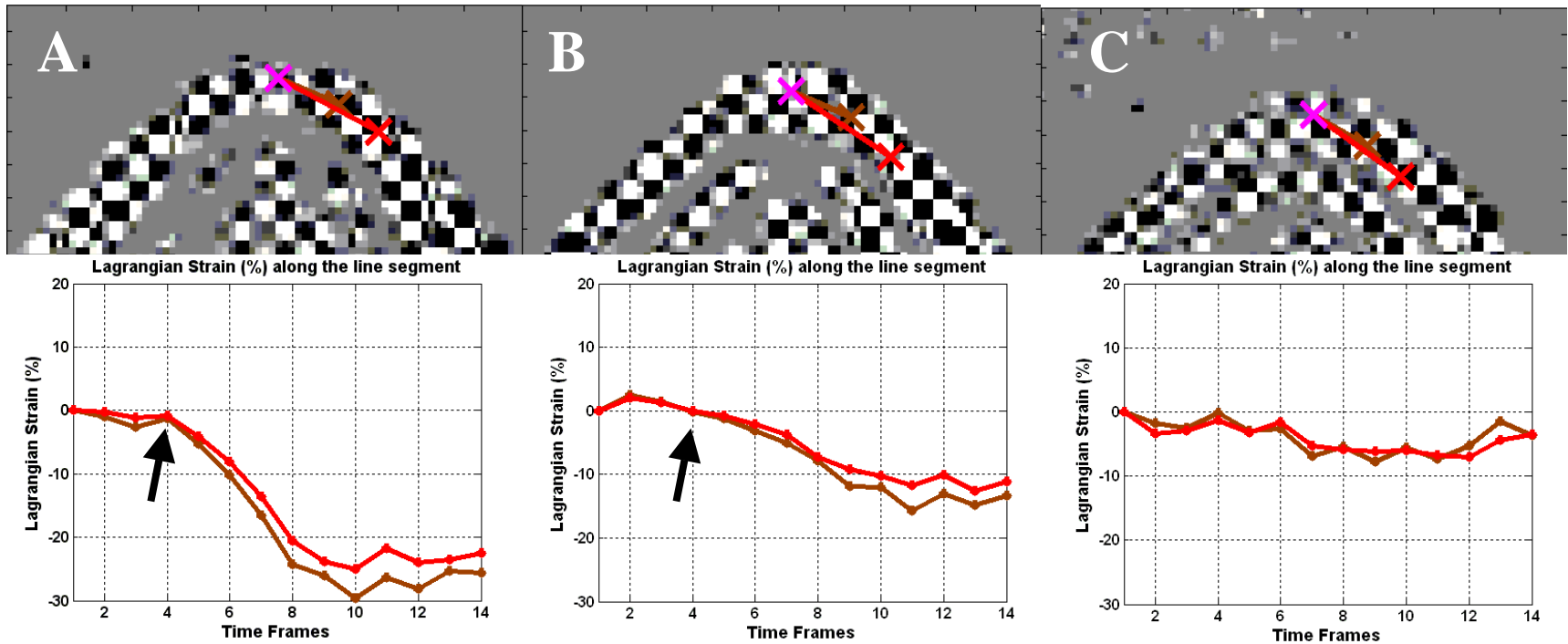


Fig. 12 A, B show lip compression starting from frame 4 for /u/. This suggests that other muscles start to compress ahead of those seen on coronal slices. The medial compression is stronger as seen in brown lines.

# Sagittal Strains Confirm Muscles

## SAGITTAL

- Fig. 13A: Subject starts transition from /i/ to /u/. Compression vectors seen in inferior lip corresponds to the mentalis and orbicularis seen in hr-MRI (see Fig.3).
- Fig. 13B: Protrusion of the lips for /u/ is maximal. There is a predominance of expansion vectors

Onset of /u/ - frame 4

Maximal /u/ - frame 9

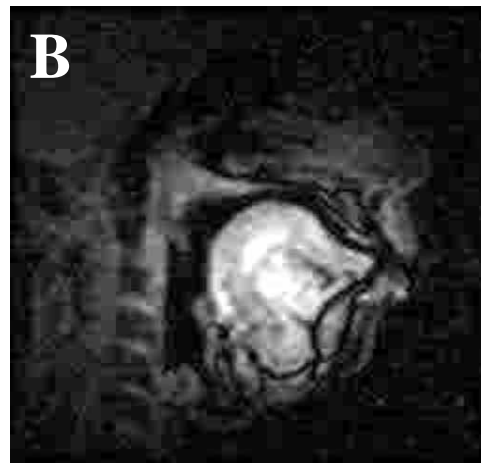


Fig. 13

Principal strains

■ compression

■ expansion

Compression, OO. m.

Compression, mentalis m.

Labial expansion

# Lagrangian Strains Shows Expansion for /i/ and /u/

## SAGITTAL

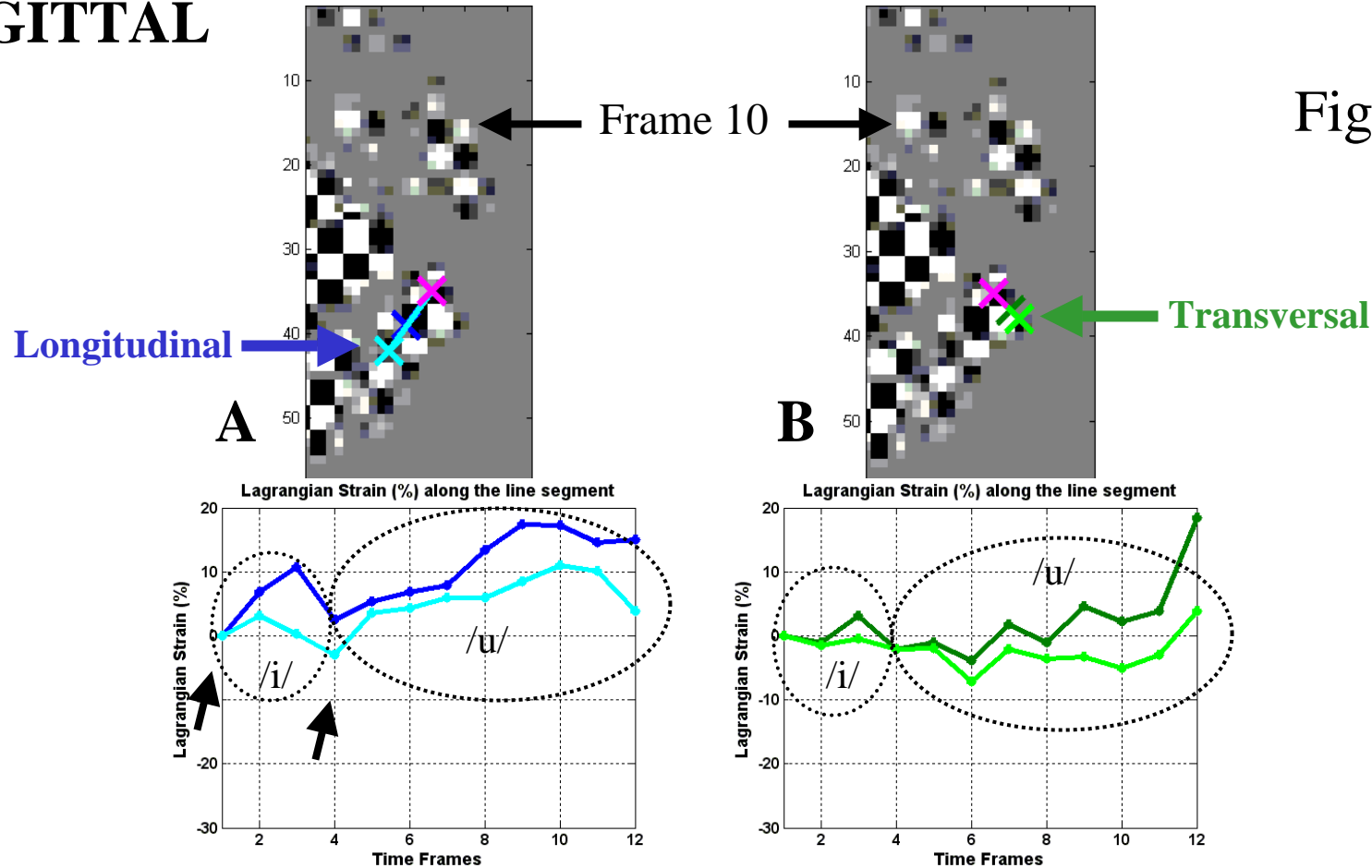


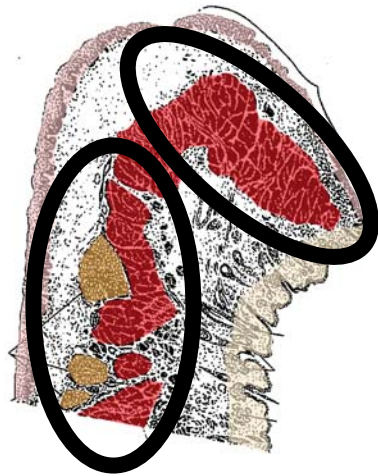
Fig. 14

- Fig. 14A: There is a longitudinal increase in distance at the beginning of /i/ (frame 1) and /u/ (frame 4) as shown in arrows.
- Fig. 14B: Transversal increase and decrease is seen.

# Lip Movement from /i/ to /u/ shows:

- Lower portion of the lower lip starts to compress at first (Fig.12 – time frame 4) then followed by anterior and upper portion of the lower lip (Fig.10 – time frame 6).
- These findings suggest that more muscles than orbicularis oris muscle are involved in the protrusion of the lips, such as mentalis and depressor labii oris muscles.
- Timing of compression (possibly contraction) starts from the mentalis muscle and OO. Muscle pars peripheralis area followed by compression of pars marginalis.

# Mechanisms for Protrusion



dense  
marginal fibers

sparse  
peripheral fibers

- Mechanical properties of contraction of the orbicularis oris muscle contributes differently. As seen in the hr-MRI, the peripheralis seems to be distributed. So when there is a contraction of these fibers, volume increases immediately. In pars marginalis, the compact nature of these fibers leads to a tissue dislocation forward.

- Lips uses muscular hydrostat mechanism where the volume is preserved, but several deformations are possible due to their muscular structure.
- The timing of their muscle activation pattern might be the underlying mechanism for different labial shapes as seen for lip protrusion in this study.
- Further studies are necessary to understand the mechanism regarding upper lips and other labial gestures.
- We consider combined hr-MRI and t-MRI as excellent tools to understand muscular-hydrostat structures used in speech.

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# Acknowledgements

We would like to thank ATR Brain Activity Imaging Center (BAIC), Department of Radiology of the University of Maryland and Department of Electrical and Computer Engineer of the Johns Hopkins University for their technical help and suggestions.

This research was conducted as part of '*Research on Human Communication*' with funding from the *National Institute of Information and Communications Technology (NICT)* in Japan and *National Institute of Health (NIH)* in USA.