A Study on the Inner Sturcture of the Tongue for Production of the 5 Japanese Vowels by Tagging snapshot MRI; a Second Report

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Introduction

The purpose of this experiment was to determine the contraction of the tongue-related muscles during the production of the 5 Japanese vowels by tagging snapshot MRI, a newly developed method by which the displacement of the tissue of the tongue can be visualized by labelling some parts of the tissue.

In the last issue(Kumada et al.), we discussed the contraction of the tongue related muscles of single subject in the mid-sagittal plane. In this paper, we obtained the images of 2 subjects to test the intersubject variety.

Method

We used a whole body MR imager (Sigma, software version 4.6; GE Medical Systems, Milwaukee) operating at 1.5T, with standard, actively shielded gradients(10mT/m, 600 sec rise time to full scale). The technical details of the tagging snapshot MRI are described in Niitsu,Campeau et al. and Niitsu,Kumada et al..

The tagging snapshot pulse sequence had three components:a contrast preparation pulse, subsequent tagging pulses and a data acquisition phase. It takes less than 2 seconds to take an image.

The tongue was at the reference position during a preparation pulse and tagging pulses. In the reference position in this experiment, the tongue tip touched the upper incisors with the dorsum touching the palate intentionally in order to obtain a consistent position which is essential to compare the articulatory gestures for different vowels. Between the end of tagging pulses and the onset of a data acquisition phase, a test vowel(one of the 5 Japanese vowels) was produced. And during a data acquisition phase, the utterance was maintained steadily.

In tagging pulses, the tagged areas were labeled as horizontal and/or vertical straight stripes with high intensity. When the tongue kept its reference position throughout all phases, an image with straight stripes could be obtained. When a vowel was uttered, the stripes were displaced, indicating the displacement of the tissues.

35-year-old(subject 1) and 30-year-old(subject 2) Japanese males served as the subject. Images of the 5 Japanese vowels and the reference position were obtained in the mid-sagittal plane of both subjects(Fig.1 and 2).

For the quantitative analysis, 6 anatomically relevant lines were drawn in the images in the mid-sagittal plane(Fig.4 and 5). The length of these lines were measured and the results are given in Tables 1 and 2. We suppose that a shortening of a line means a contraction of a muscle.

Voice recording was also held in an anechoic chamber. The phonatory condition was the same as that in taking MR images except for the acoustic condition. Namely, the posture of the subjects was supine and the vowels were produced after the reference position. The duration of the vowels were about 3 seconds.

Result

1. outer and inner configureational changes

Fig.1 and 2 are the images of subject 1(sub.1) and 2(sub.2) respectively taken in the mid-sagittal plane.

During the utterances of /a/, /i/, /u/ and /e/, configurational changes of the tongue of 2 subjects appeared almost the same.

During the utterance of /a/, the tongue took the lowest position. But in the horizontal axis the tongue remained in the same position as the reference position. The vertical stripes became shorter than at the reference position, while the length of the horizontal stripes remained nearly the same as at the reference position. The horizontal stripes and the dorsum showed concave lines. These findings would seem to indicate that the anterior part of the tongue was pulled down to the chin.

During the utterance of /i/, the tongue took the highest and most anterior position. The lower horizontal stripes became very short, which probably shows the contraction of the middle and the posterior parts of the genioglossus muscle. The higher horizontal stripes showed convex curves ,which may show that they were passively curved.

During the utterance of /u/, the tongue took a 'middle position'(neither to the back nor to the front, higher than /a/ but lower than /i/) and the length of both the horizontal and the vertical stripes became shorter in general.

During the utterance of /e/, the shape and the position of the tongue appears to have been similar to that for /i/, but lower.

The configurational change in the tongue of sub.1 during the utterance of /o/ was the most impressive. The upper half of the tongue appears to have been pulled back while the lower half took almost the same position as the reference position. Thus, a kind of a 'landslide' can be seen at the bottom of the mouth. This 'landslide' was probably caused by the contraction of the styloglossus muscle. However, in sub.2, the upper half of the tongue appears to be pulled back with less degree than sub.1. 'Landslide' can not be seen in sub.2.

2. muscle contraction

Fig.3 is the ordinary MRI of the tongue of sub.1 in the mid-saggital plane. It took

20 minutes to take this image in order to obtain a higher spacial resolution. In this image, we can see the fat tissues which delineate the genioglossus and the superior-longitudinalis muscles.

By this image and the previous anatomical study of Miyawaki, 6 anatomically relevant lines were drawn in the images in the mid-sagittal plane for quantitative analysis(Fig.4 and 5). We measured the lengths of these lines(Table 1 and 2). We suppose that a shortening of a line means a contraction of a muscle.

Lines No.1(L1), No.2(L2), No3(L3) and No.5(L5) may represent the fibers of the anterior, middle and posterior part of the genioglossus muscle (GGa, GGm and GGp) and the superior-longuitudinalis muscle(SL) respectively. Line No.4(L4) and No.6(L6) are also included as the representatives of the crossing stripes. These 2 lines might represent indirectly the fibers of the verticalis(V) and the inferior-longuitudinalis(IL) muscles respectively. These 2 muscles are not in the mid-sagittal plane.

During the utterance of /a/: L1, L4 and L5 in both subjects and L2 in sub.2 became much shorter. This may indicate the contraction of GGa, V and SL (and also GGm in sub.2), which may have caused the shortening of the tongue in the verticalis axis.

During the utterance of /i/: L2 and L3 in both subjects and L5 in sub.2 became much shorter, which may indicate that GGm and GGp (and also IL in sub.2) contracted to pull the tongue toward the chin to make the tongue shorter in the longitudinal axis. The high position of the tongue may have been caused passively by the contraction of GGm and GGp.

During the utterance of /u/: In sub.1, L1, L3 and L6 became much shorter.In sub.2, on the other hand, 6 lines became shorter almost to the same degree. Thus, it may be GGa, GGp and IL chiefly in sub.1 and 6 muscles all in sub.2 that made the tongue shorter both in the vertical and the longuitudinal axis.

During the utterance of /e/: The tongue position for /e/ was lower than that for /i/ in both subjects. It may be because that GGm didn't contract to such an extent as in /i/ in both subjects. Besides, contraction of SL in sub.1 and of V in sub.2 may have made the tongue shorter in the vertical axis.

During the utterance of /o/: In sub.1, L3 became shorter, which may indicate a contraction of GGp to pull the bottom of the tongue against the contraction of SG to pull back the upper part of the tongue as a result of the 'landslide' at the level of the bottom of the mouth. The shortening of L5 may indicate the contraction of SL to make the upper part of the tongue tight. Also in sub.2, L3 and L5 became shorter but the shortening of L1 and L4 are remarkable. It may be because of the contraction of GGa and V that the remarkable 'landside' caused by SG can not be seen in sub.2.

3. sound analysis

In Table 3 and 4, the fundamental frequencies(f0) and the formants of vowels of 2 subjects are given. All F1 and F2 of both subjects are within the range of Japanese vowels.

Discussion

As a whole, the data obtained from MRI of 2 subjects are almost the same with each other. But there are some differences between 2 subjects. These differences may be due to the following reasons.

(1)In Japanese (and any other languages), F1 and F2 of vowels have some range. Then, the tongue doesn't have to have exactly the same outer configuration to produce a vowel.

(2)To obtain almost the same outer configuration, there may be several combinations of contractions of the muscles.

The difference of (the inner and) the outer configuration of /o/ between 2 subjects was rather remarkable. It may be due to the reason (1). The difference of F2 was also remarkable.

An example of (2) may be seen in /u/. The combination of contractions of the muscles were different but the outer configurations were almost the same between 2 subjects.

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Figure Captions

FIG.1
MR images of sub.1 in the mid-sagittal plane during production of the 5 Japanese vowels

FIG.2
MR images of sub.2 in the mid-sagittal plane during production of the 5 Japanese vowels

FIG.3
Ordinary MR image of the reference position of sub.2. The fat tissues delineating the genioglossus and the superior-longuitudinalis muscles can be seen.

FIG.4
Schemata of MR images of sub.1 with 6 lines imposed. Each of the 6 lines has an anatomical referent.

FIG.5
MR images of sub.2 with 6 lines imposed. Each of the 6 lines has an anatomical referent.

No.	r.p.	/a/	/i/	/u/	/e/	/o/
1	100	77	100	91	97	123
2	100	93	77	98	86	114
3	100	102	69	83	81	93
4	100	73	121	115	109	118
5	100	84	103	98	89	94
6	100	107	89	84	91	71

Table 1. Sub. 1: Relative lengths of 6 lines compared to the reference position (=r.p.=100).

No.	r.p.	/a/	/i/	/u/	/e/	/o/
1	100	64	94	86	93	77
2	100	74	79	88	83	94
3	100	95	65	72	80	90
4	100	55	99	82	89	73
5	100	83	96	86	91	91
6	100	91	67	82	78	93

Table 2. Sub. 2: Relative lengths of 6 lines compared to the reference position (=r.p.=100).

	/a/	/i/	/u/	/e/	/o/
f0	140	140	142	144	144
F1	683	254	271	397	410
F2	1229	2213	940	1944	1254
F3	2544	3144	2204	2878	2289

Table 3. Sub.1: Fundamental frequency and formants

	/a/	/i/	/u/	/e/	/o/
f0	102	104	105	101	102
F1	528	254	254	411	410
F2	1032	1993	1034	1699	1514
F3	2214	2539	2102	2354	2518

Table 4. Sub.2: Fundamental frequency and formants

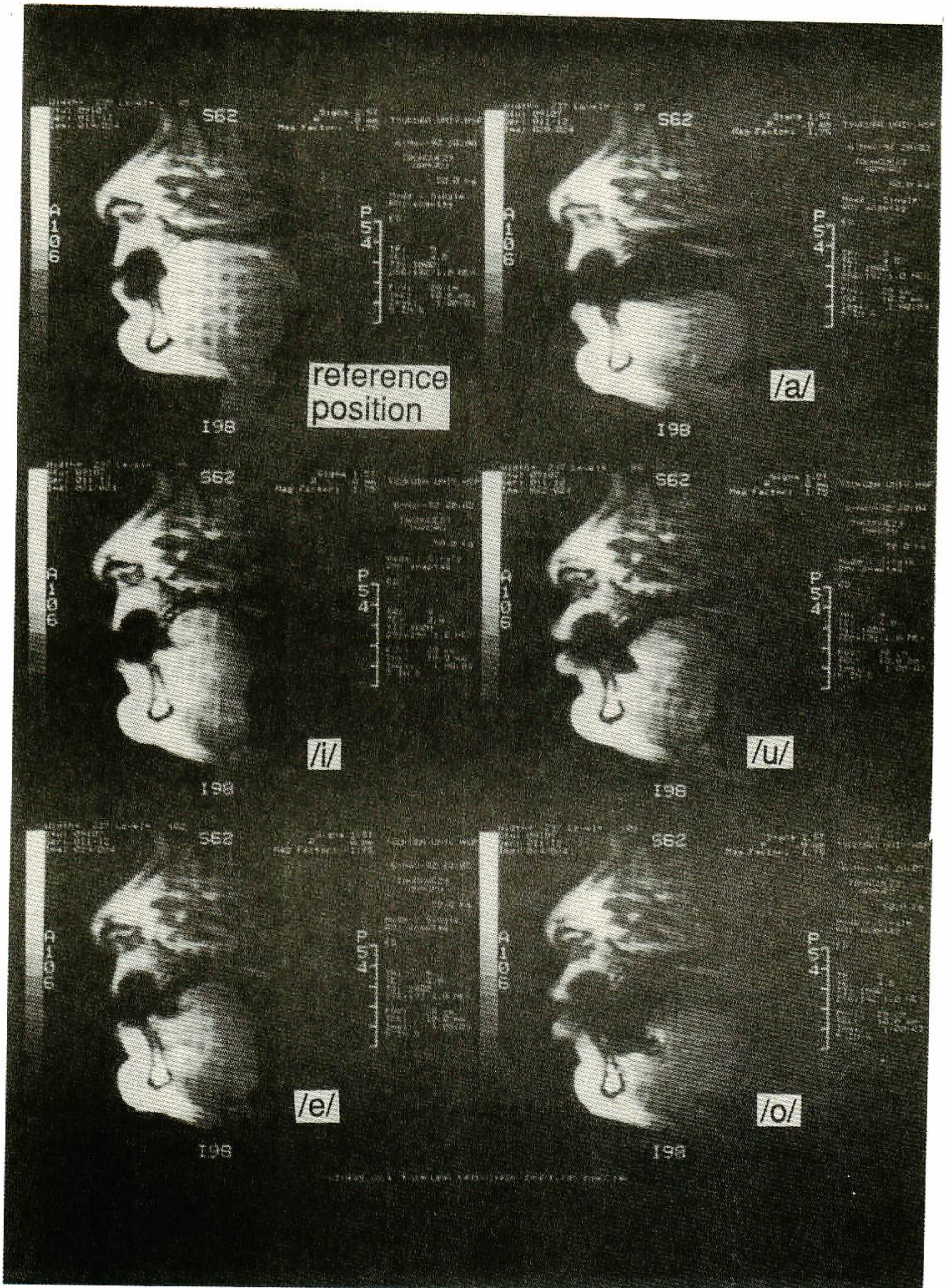

FIG.1

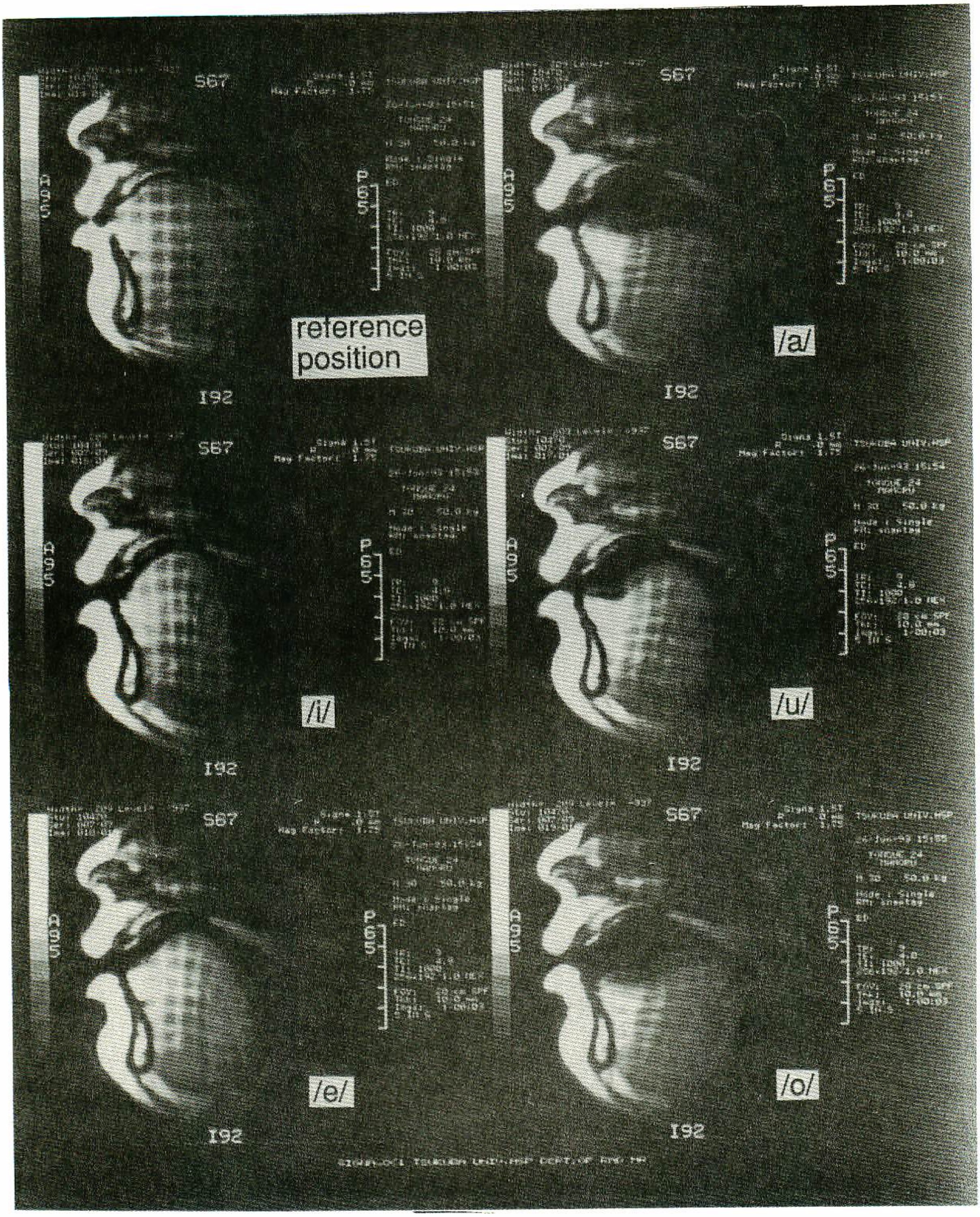

FIG.2

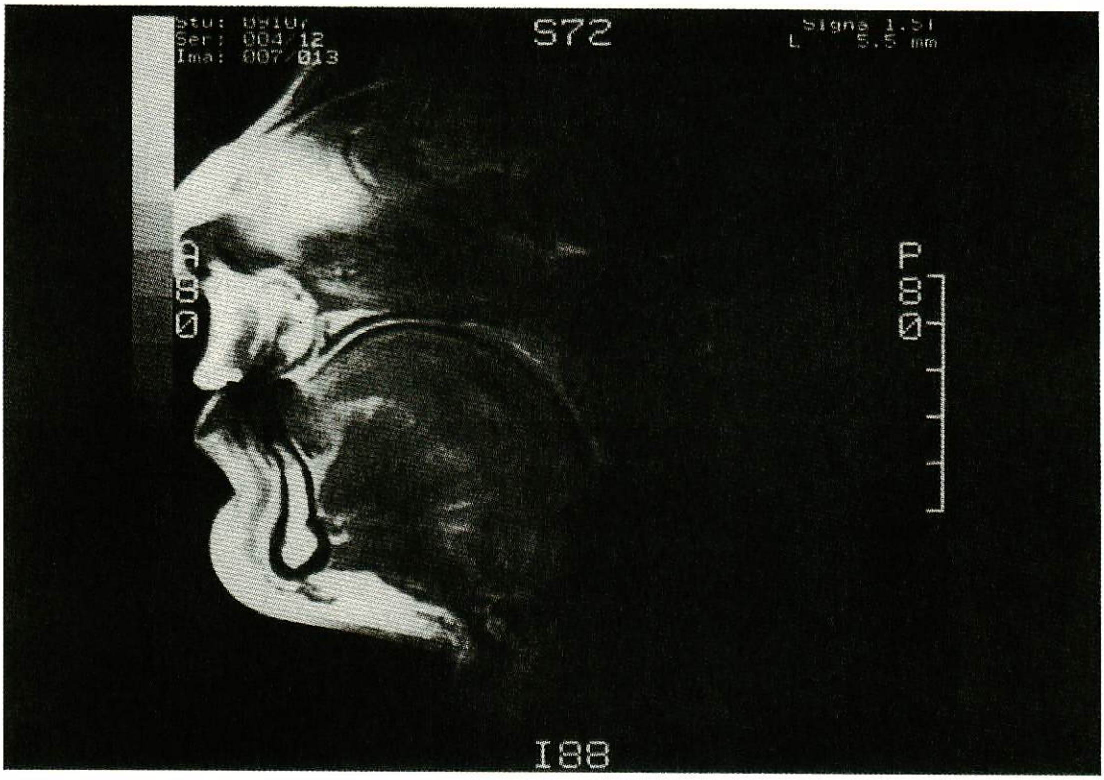

FIG.3

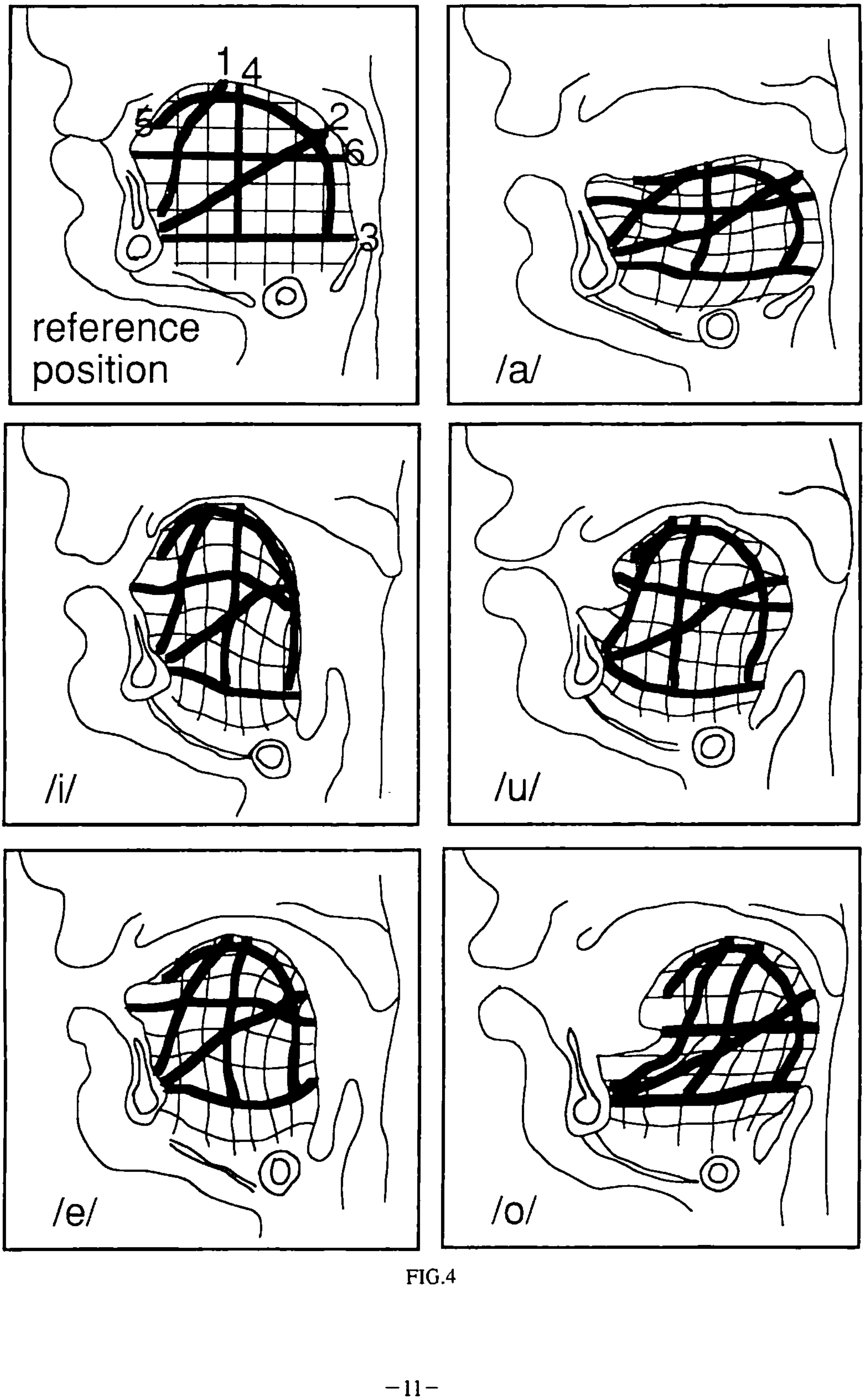

FIG.4

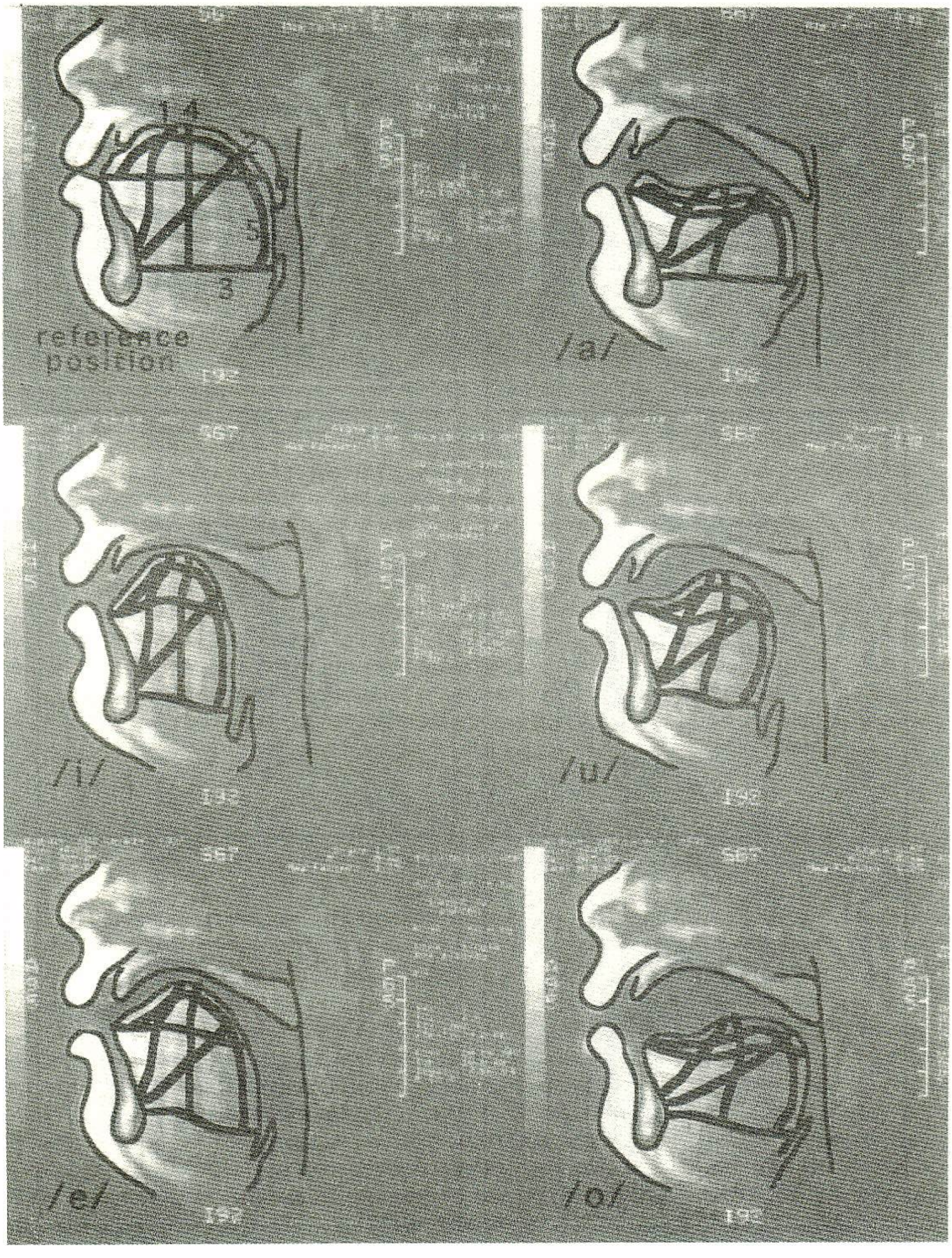

FIG.5