

Cantilever-type force-sensor-mounted palatal plate for measuring palatolingual contact stress and pattern during speech phonation

Masafumi MATSUMURA¹⁾, Takuya NIIKAWA¹⁾, Takao TANABE¹⁾,
Takashi TACHIMURA²⁾, and Takeshi WADA²⁾

- (1) Division of Information and Computer Sciences, Graduate School of Engineering,
Osaka Electro-Communication University, 18-8, HATSU-CHO, NEYAGAWA, 572-8530 JAPAN.
E-mail : matumura@amlab.osakac.ac.jp
(2) Division for Oral-Facial Disorders, Faculty of Dentistry, Osaka University,
Yamada-Oka 1-8, SUITA, 565-0871 JAPAN

ABSTRACT

A 15-cantilever-type force-sensor unit is presented for the measurement of palatolingual contact stress and pattern during palatal consonant phonation. The force sensor unit is composed of a strain gauge and a cantilever, and is embedded in a thin palatal plate attached to the human hard palate. It is 3 mm wide, by 5 mm long, and 1.3 mm thick. The output of the force sensor unit at the low stress range of 0-64 kPa (0-5 gw) is proportional to the stress applied to the force sensing unit, with nearly no hysteresis. Measurement error of the force sensor is less than 1.7%. Error by mechanical interference among cantilever-type force sensors is less than 0.2%. The presented 15-cantilever-type force-sensor-mounted palatal plate allows for ready observation of the dynamic aspect of the palatolingual contact stress and patterns during the phonation of consonants.

1. INTRODUCTION

Palatolingual contact stress and pattern are important parameters in the investigation of the dynamic properties of human tongue motion during palatal consonant phonation and swallowing. Palatolingual contact can be detected by dynamic palatometry, a practical technique using electrodes embedded in a thin palatal plate that adheres to the hard palate [1]. The palatogram obtained by dynamic palatometry is widely used for speech analysis and the production of speech aids. The dynamic palatometry based on the electrical impedance of palatolingual contact detects binary palatolingual contact patterns, but does not have the ability to measure the palatolingual contact stress.

Recently, we developed a prototype system capable of providing continuous measurement of palatolingual contact stress and pattern during consonant phonation [2-4]. The system consists of three components : a fixed-beam-type force-sensor-mounted palatal plate, a multichannel amplifier to supplement the strain gauge, and a computer. The force sensor is composed of a strain gauge and a fixed beam, mounted together on a palatal plate that is attached to the hard palate. When the tongue touches the force sensor during consonant phonation, palatolingual contact stress is detected from the strain produced in the fixed beam of the force sensor. In prior research, palatolingual contact stress and speech signals of an adult male have been measured during phonation of the consonants.

In this paper, we present a new cantilever-type force sensor of the high sensitivity, and capable of accuracy in measuring palatolingual contact stress and pattern. Since this force sensor is a small and independent unit, it is possible to select a force sensor that has approximately the same characteristics, and mount it to a palatal plate. The following section explains the static and dynamic characteristics of the cantilever-type force sensor unit, and illustrates palatolingual contact stress and pattern during the phonation of consonants.

2. METHODS

2.1. Cantilever-type force sensor

A force sensor for measuring palatolingual contact stress and pattern must be sufficiently small and capable of being mounted on the arbitrarily curved surface of the human hard palate. A strain gauge is made up of piezoresistive sensors and is extensively used for sensing position, force, pressure, and mass in industrial areas. Recently, a smaller, thinner strain gauge with a resistance grid of several millimeters has been made available. In our study, this small-sized strain gauge is used in the development of a highly sensitive force sensor that meets the demands of use on the human hard palate. A cantilever is a beam with one side fixed and a protuberance bonded to its other side. If a force F is applied at the protuberance, the strain produced in the beam is directly proportional to the applied force F .

Figure 1(a) shows the top view and cross section of a cantilever-type force sensor unit. The cantilever-type force sensor, which consists of a strain gauge and a cantilever, is mounted on a palatal plate attached to the human hard palate. The span of the cantilever is 2 mm, it is 0.5 mm thick, and it is made of stainless steel. The strain gauge is bonded on the other side of the protuberance of the cantilever. The base size and the resistance grid size of the strain gauge are 1 mm×0.68 mm and 4.2 mm×1.4 mm, respectively. To waterproof the strain gauge, its surface is covered with a thin film. The force sensor is put in a metallic case to prevent direct contact between the cantilever and the hard palate. The size of the force sensor unit is 3 mm×5.5 mm, and the force-sensor-mounted palatal plate is 1.3 mm thick.

The palatal plate shown in figure 1(b) is a thin plastic plate that is shaped to attach tightly to the subject's hard palate by thermoforming. The thickness of the palatal plate is 0.5 mm. When

the tongue contacts the active area of the bonded protuberance, a plastic cylinder 1 mm in height and diameter, the palatolingual stress is concentrated in a specific spot on the cantilever. Because the active area of the protuberance is small (0.785 mm^2), the tongue surface can be regarded as contacting the active area of the protuberance uniformly.

Therefore, when the palatal plate is pressed by the surface of the tongue, the palatolingual stress in the position of the force sensor is measured from the strain produced in the cantilever. Multiple force sensors can be mounted to arbitrary positions on the palatal plate, and the palatolingual contact stress and pattern can be obtained by use of the multiple force sensors.

2.2. Measurement system

We have developed a 15-force-sensor-mounted palatal plate for measuring palatolingual contact stress and pattern during consonant phonation. Figure 1(b) shows the appearance of the 15-force-sensor-mounted palatal plate, which measures palatolingual contact stress and pattern at the anterior palatal surface. The force sensors are placed at approximately 5 mm intervals on the hard palate. The wires for the force sensors are extended out through the posterior edge of the palatal plate and around the corners of an upper molar. The strain gauge of each force sensor is connected to one arm of a full bridge circuit. Voltage changes across the bridge diagonal, caused by resistance changes of the strain gauge, are amplified by an amplifier. Each force sensor was carefully adjusted so that its normal axis was perpendicular to the surface of the palatal plate. A recording system was designed to measure speech signals and the palatolingual contact stress simultaneously at multi-points of the palatal plate.

Figure 1(c) shows the three parts of the recording system: a 15-force-sensor mounted palatal plate, a multichannel strain meter for the strain gauge, and a computer for data collection and signal processing. The output of the multichannel amplifier (i.e. output of the force sensors) and speech signals are digitized at a rate of 2.36 kHz and converted to 16 bits digital signals. The palatolingual contact stress is calculated from the output of the force sensor on the basis of the relationship between the force applied to the protuberance of the force sensor and that output. Palatolingual contact stress at an arbitrary position on the hard palate is estimated from measured data and positions of the force sensor by using linear interpolation.

3. RESULTS

3.1. Characteristics of the cantilever-type force sensor

To evaluate static characteristics of the force sensor unit, we measured both applied stress and output of the force sensor when the load applied to the protuberance was increased at 0.5 gw intervals from zero to 5 gw, and then decreased continuously to zero. The stress is the amount of the applied load divided by the active area of the protuberance. Results show that the output of the force sensor at the low stress range of 0-64 kPa (0-5 gw) was proportional to the stress applied to the force sensor, with nearly no hysteresis. Measurement error of the force sensor was less than 1.7%.

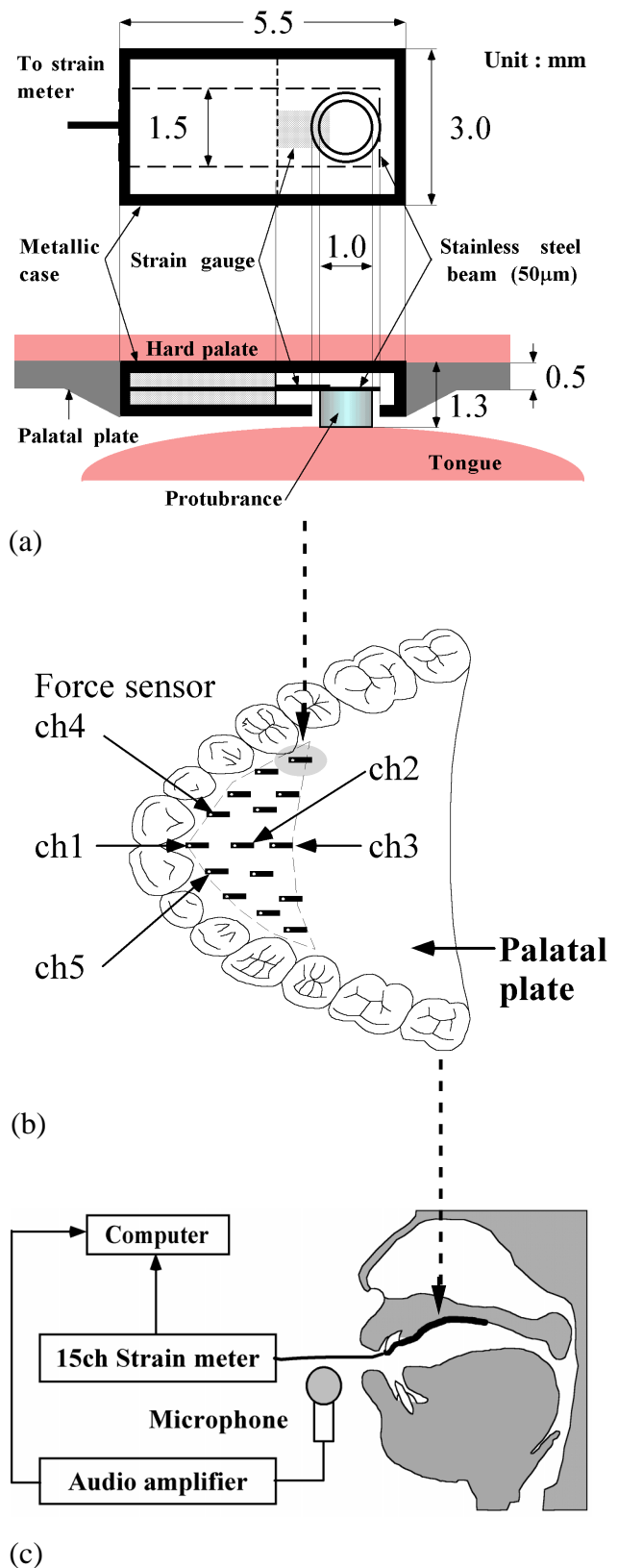


Figure 1: Cantilever-type force sensor unit (a), 15 force sensor mounted palatal plate (b), recording system (c).

	ch1	ch2	ch3	ch4	ch5
ch1	100	0.06	0.03	0.03	0.01
ch2	0.02	100	0.20	0.05	0.03
ch3	0.10	0.02	100	0.06	0.10
ch4	0.01	0.03	0.02	100	0.0
ch5	0.04	0.07	0.07	0.04	100

Table 1: Error (%) by mechanical interference among force sensors shown in figure 1(b).

For purposes of evaluating mechanical interferences among multiple force sensors, when a load of 10gw was applied to the protuberance of each force sensor ch1-ch5 shown in figure 1(b), the output of the other force sensors was measured. In Table 1, the row headings indicate channel numbers of the force sensor to which the load was applied. The column headings indicate channel numbers of the force sensor from which output was measured. Outputs of the force sensors were normalized by the output of the force sensor to which the load was applied. Error by mechanical interference among cantilever-type force sensors was less than 0.2%, negligible small relative to the measurement error of force sensor, and it was very low relative to error by mechanical interference among fixed-beam-type force sensors [2].

We next conducted an experiment for investigating the influence of saliva on the static and dynamic characteristics of the force sensor. The static characteristic of the force sensor was measured in a physiological saline solution (0.9% concentration and 0.6 pH) with the approximate electrical and chemical properties of saliva. In the physiological saline solution, the resulting slope change of the static (stress-output) characteristic was less than 3%, implying that there is no significant influence of saliva on the static characteristic of the force sensor. The dynamic characteristic of the force sensor was determined by step response in the physiological saline solution. The force sensor's response was measured on the sudden removal of the 5 gw force applied to its protuberance. Results indicate that the time elapsing during the change from a 90% to a 10% level output was 0.63 ms.

Therefore, the static and dynamic characteristics of the force sensor can be considered more than adequate for purposes of studying palatolingual contact stress and pattern during consonant phonation.

3.2. Palatolingual contact stress and pattern during consonant phonation

By means of the presented system, an experiment for measuring the palatolingual contact stress and pattern has been conducted. The palatolingual contact stress and pattern of an adult male subject who had no history of speech disorder were measured during Japanese consonant and vowel phonation (CV: where C=t, tch, d, n, r, and s; and V=a, i, u, e, o). Each test word was uttered at a natural speaking rate.

Because the cantilever-type force-sensor-mounted palatal plate is thin and is attached tightly to the subject's hard palate, the placement of the palatal plate had approximately no effect on speech phonation.

Figure 2 illustrates a typical time course for the palatolingual contact stress and pattern in the phonation of /tchi/. The upper figure shows a speech signal and the lower figures show palatolingual contact stress and pattern at the time t1-t8, with equal intervals (50 ms). The results show that (1) the maximum values of the palatolingual contact stress during the consonant phonations ranged from 5 to 35 kPa (0.4-2.7 gw), and that (2) in the case of consonant /tch/ phonation, when the palatolingual contact stress vanished, a burst sound was produced.

The time resolution of the presented system is 0.43 ms, much higher than the reported time resolution of the high speed palatography [5]. The proposed system thus allowed for ready observation of the dynamic aspect of the palatolingual contact stress and patterns.

4. CONCLUSIONS

This study was performed (1) to develop a cantilever-type force sensor unit, (2) to test the reliability of such a unit, and (3) to measure palatolingual contact stress and pattern during consonant phonation. As determined by the static and dynamic response data obtained, the cantilever-type force-sensor-mounted palatal plate possesses the performance properties required to detect palatolingual contact and stress during consonant phonation. A prototype system, consisting of a 15-force-sensor-mounted palatal plate, a multichannel amplifier, and a computer, has been developed. The proposed system allowed for ready observation of the dynamic aspect of the palatolingual contact stress during the phonation of consonants.

Furthermore, since the presented force sensor unit is small, technically it is possible to develop a force-sensor-mounted palatal plate capable of measuring palatolingual stress at 32 or more points on the hard palate for spatial high resolution and measurement of a wide area.

5. REFERENCES

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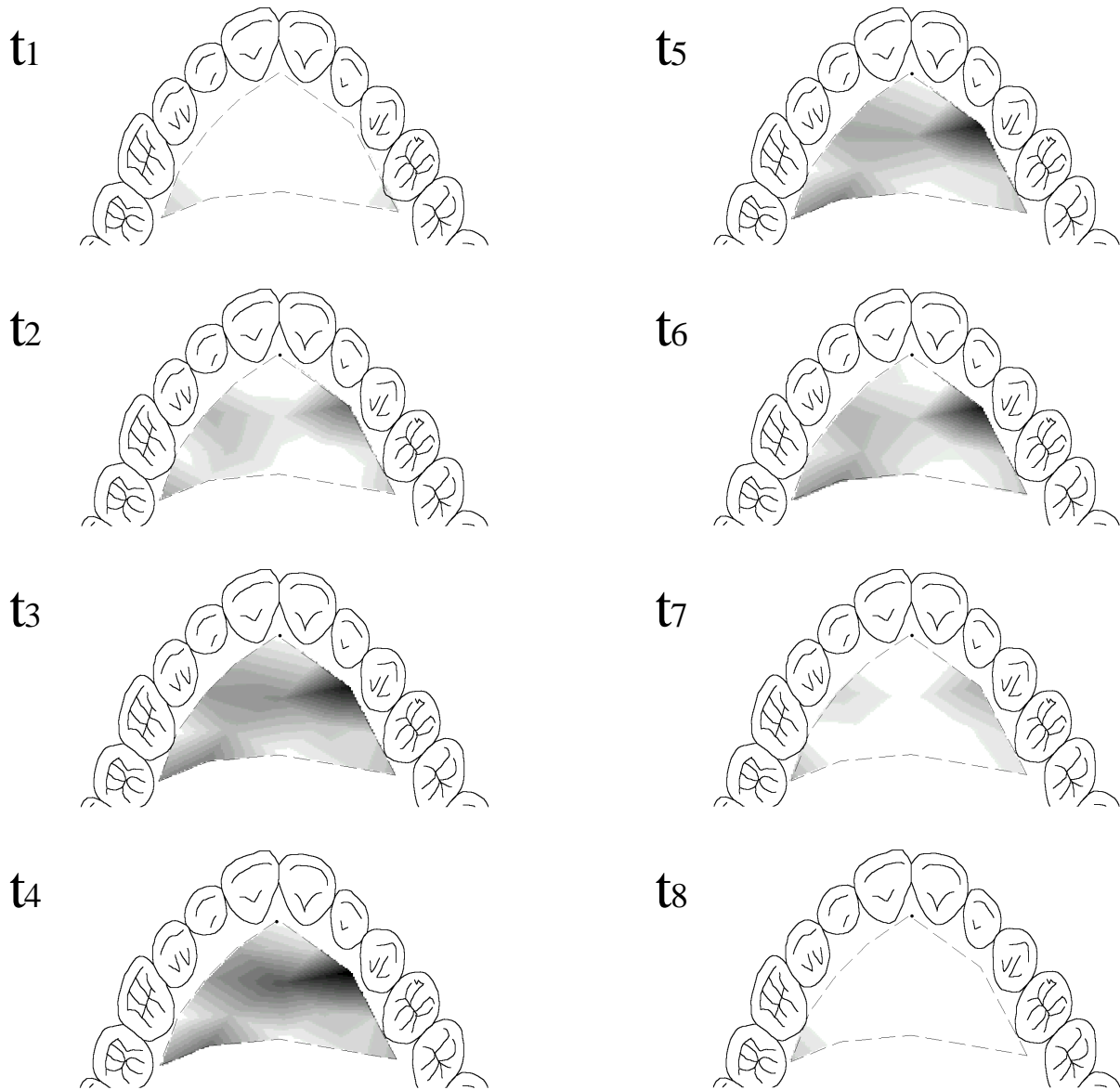
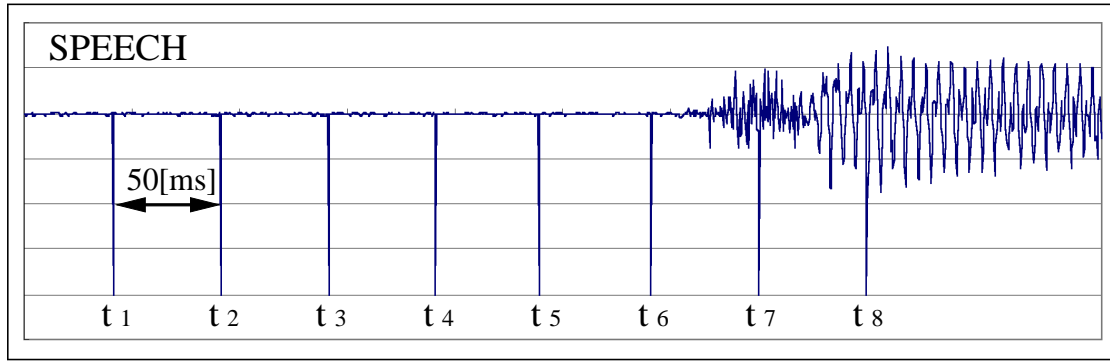


Figure 2: Palatolingual contact stress and patterns during the phonation of consonant /tchi/. A region of palatal surface that put the force sensors is shown with a dotted line. Palatolingual contact stress at the region is determined from measured data and positions of the force sensors by using linear interpolation. The palatolingual contact stress range of 0-35kPa is indicated by gray level.