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Measument of Palatolingual Contact Pressure During Consonant Productions Using Strain Gauge Transducer Mounted Platal Plate

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ABSTRACT

This paper deals with the measurement of palatolingual contact stress and pattern during consonant productions using a force sensor mounted palatal plate. The force sensor is composed of a strain gauge and a fixed beam that are mounted together in a palatal plate that is attached to the hard palate. The palatolingual contact stress is concentrated in a spot on the fixed beam by a protuberance bonded on the fixed beam. When the tongue touches the protuberance of the force sensor, the palatolingual contact stress on the force sensor is detected from the strain produced in the fixed beam. By mounting multiple force sensors, the palatolingual contact stress and pattern can be obtained. We have developed a prototype system, which consists of a five-force-sensor mounted palatal plate, a multichannel amplifier for a strain gauge and a computer. The force sensor mounted palatal plate is 1mm in thickness. The five-force-sensors are placed approximately at a 6mm interval along the midsagittal line of the hard palate. The most anterior sensor is located 5mm posterior to the alveolar ridge. Output of the force sensor was proportional to the stress applied to the fixed beam and had no hysteresis. Measurement error of the force sensor was less than 2% and an error by mechanical interferences among the sensors was less than 5.4%. The palatolingual contact stress and pattern for an adult male were measured during the productions of consonants /t/,/d/,/n/. Using the proposed system, dynamic aspect of the palatolingual contact stress in time-domain and space-domain were readily observed.

1. INTRODUCTION

Several techniques for investigating human speech productions have been reported in speech science literatures focusing on the tongue as the primary articulatory organ. The profile and motion of the tongue have been measured by a computer-controlled X-ray technique [1], a photoelectric device [2], and a ultrasonic imaging [3]. A strain gauge is a resistive elastic sensor whose resistance is a function of applied strain. A strain gauge transducer has been developed to monitor jaw, lip, and velum movements [4]. Three dimensional shapes of vocal tract and nasal cavity have been measured by the magnetic resonance imaging [5,6].

The palatolingual contact stress and pattern are important parameters for evaluating the dynamic properties of the human tongue during the palatal consonant productions. The dynamic palatometry is a practical technique which detects the palatolingual contact with electrodes imbedded in a thin palatal plate that adheres to the hard palate [7]. The palatogram obtained by the palatometry is widely used for speech analysis and speech aids. In most sensors, the palatolingual contact stress is not directly converted into an electrical signal. Some intermediate steps are usually required. Several transducers for the force sensing have been developed for biomedical applications. In the traditional approach, however, there is no system capable of measuring the palatolingual contact stress and pattern in the production of consonants.

The purpose of this paper is to develop a force sensor mounted palatal plate for measuring the palatolingual contact stress and pattern during consonant productions. The force sensor is composed of a strain gauge and a fixed beam that are mounted together in the palatal plate that is attached to the hard palate. When the tongue touches the force sensor during consonants productions, the palatolingual contact stress is detected from the strain produced in the fixed beam of the force sensor. We have developed a prototype system capable of providing continuous measures of the palatolingual contact stress and pattern during consonant productions. The system consist of three parts, a five-force-sensor mounted palatal plate, a multi-channel amplifier for a strain gauge and a computer. The palatolingual contact stress and speech signal of an adult male are measured during the productions of consonants /t/,/d/,/n/.

In the following section, we will describe the force sensor mounted palatal plate. In section 3, the static and dynamic characteristics of the force sensor will be explained and the palatolingual contact stress and pattern during the productions of consonants /t/,/d/,/n/, will be showed.

2. METHODS

2.1 FORCE SENSING BY STRAIN GAUGE

The force sensor which is mounted on the hard palate requires thin type and capability of mounting to the surface of the hard palate (arbitrary curved surface). The strain gauge is one of piezoresisitive sensors and widely used for sensing position, force, and pressure in industrial areas. Recently, a small and thin type strain gauge in which the size of the resistance grid is several millimeters is offered. In this study, a high sensitive force sensor which meets the requirements by using the strain

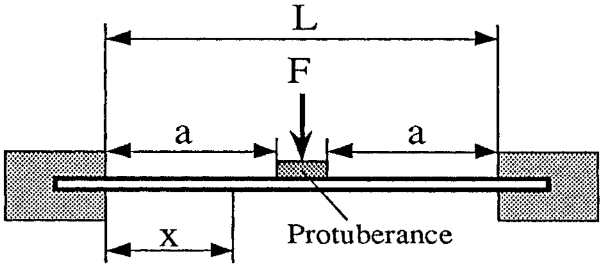

Figure 1 Model of fixed beam.

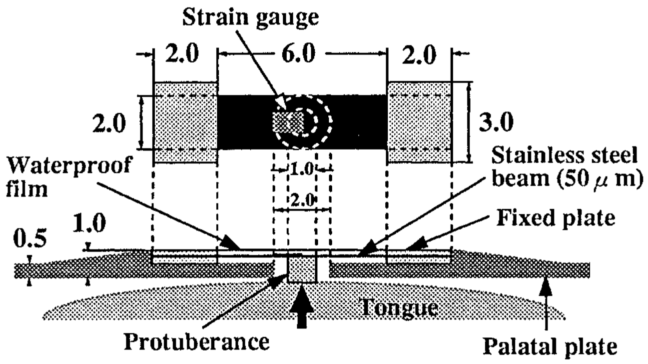

Figure 2 Cross sectional view of force sensor mounted palatal plate. (unit : mm)

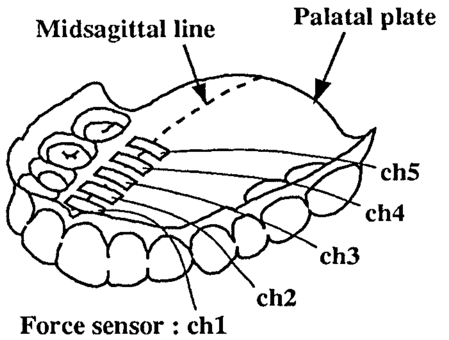

Figure 3 Appearance of five sensor mounted palatal plate.

gauge was developed.

Figure 1 shows a fixed beam with both ends was fixed and a protuberance bonded on the center of the beam. If a force F is applied at the protuberance, a bending moment M and a strain $\varepsilon(x)$ that are produced in the fixed beam are represented by an equation (1). The equation (1) indicates that the strain produced in the fixed beam is directly proportional to the applied force F .

$$\varepsilon(x) = \frac{h}{EI} M(x) \qquad (1)$$

Where,

$$M(x) = \begin{cases} \left\{\left(\frac{L}{2} - a\right)x - \frac{L^2}{12} + \frac{a^2}{2} - \frac{a^3}{3L}\right\} q & (0 < x < a) \\ \left\{\left(\frac{L}{2} - a\right)x - \frac{L^2}{12} + \frac{a^2}{2} - \frac{a^3}{3L} - \frac{(x-a)^2}{2}\right\} q & (a < x < \frac{L}{2}) \end{cases}$$

$q = F/S$ (S : active area of protuberance)

Youngs' modulus is represented by E, a moment of inertia of area by I and a thickness of beam by h. This is the fundamental design formula which is determined by the span L, the thickness of a beam, and the size of a protuberance. However, because (a) bonding the strain gauge on the fixed beam slightly changes the beam's bending characteristics and (b) the resistance grid of the strain gauge is deviated from the neutral bending axis of the fixed beam, the equation (1) are slightly in error. We have experimentally determined that the equation (1) results in a calculated-observed error of less than 10%.

2.2 FORCE SENSOR MOUNTED PALATAL PLATE.

A thin force sensor which consists of a strain gauge and a fixed beam was mounted in a palatal plate that is attached to the hard palate. The principle of force sensing is based on the resistance changes of strain gauges that are bonded to the fixed beam. The palatal plate is a thin plastic plate that is shaped so as to tightly attach to the subject's hard palate by thermoforming. The thickness of the palatal plate is 0.5 mm. Figure 2 shows the cross-sectional view of a force sensor mounted palatal plate. Both ends of a beam are fixed to the palatal plate. When the tongue contacts to the active area of a protuberance bonded on the center of the fixed beam, the palatolingual stress is concentrated in a spot on the fixed beam. The protuberance is a plastic cylinder with 1mm diameter and 1mm height. Because the active area of the protuberance is small (0.785mm²), it can be considered that the tongue surface contacts to the active area of the protuberance uniformly. The span L of the fixed beam is 6mm. The fixed beam is the stainless steel with 0.05mm thickness. The strain gauges are bonded on the other side of the protuberance of the fixed beam. The base size and the resistance grid size of the strain gauge are 1mm×0.68mm and 4.2mm×1.4mm, respectively. For the waterproof, the surface of the strain gauge is covered with a thin film. The force sensor is also covered with a thin film for preventing the contact of the fixed beam and the hard palate. The size of the force sensor is 2mm×6mm and the force sensor mounted palatal plate is 1mm in thickness. According to the equation (1), when a load of 5gw is applied to the protuberance of the force sensor, the strain that is produced at the position of the strain gauge is 135 micro-strain. Therefore, when the palatal plate is oppressed by the surface of the tongue, the palatolingual stress in the position of the force sensor is measured from the strain produced in the fixed beam. Multiple force sensors can be mounted to the arbitrary position on the palatal plate and the palatolingual contact stress and pattern can be obtained by mounting the multiple force sensors.

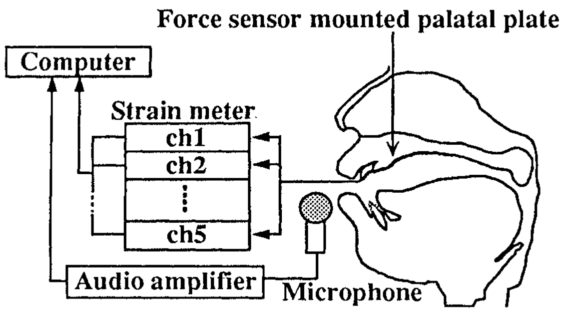

Figure 4 Block diagram of recording system.

2.3 MEASUREMENT SYSTEM.

We developed a five-force-sensor mounted palatal plate for measuring the palatolingual contact stress and pattern in the midsagittal plane during consonant productions. Figure3 shows appearance of the five-force-sensor mounted palatal plate. The force sensors are placed approximately with an equal interval along the midsagittal line of the hard palate. The most anterior force sensor is located 5mm posterior to the dental ridge and the separation distance between the force sensors is 6mm. The wires for the force sensors were extended out through the posterior edge of the palatal plate and around the corners of an upper mollar. The strain gauge of each force sensor is connected to one arm of a Wheatstone bridge circuit. Other three additional resistors are provided to determine the span of the bridge and to adjust the initial zero balance of the bridge. Voltage changes across the bridge diagonal 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 palatal plate. Recording system was designed to measure the palatolingual contact stress at

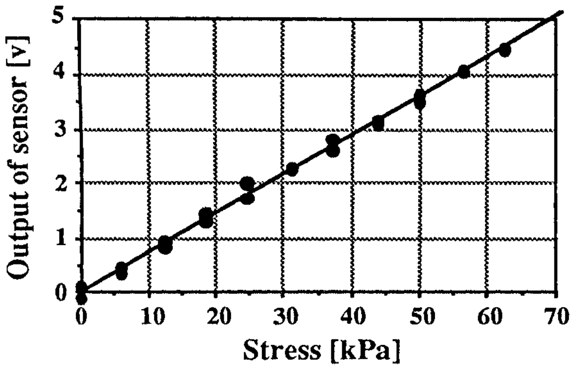

Figure 5 Relationship between applied stress and output of force sensor.

multi-points of the palatal plate and speech signals simultaneously.

Figure 4 shows a block diagram of the recording system. The recording system consists of three parts, the five-force-sensor mounted palatal plate, the multi-channel amplifier for the strain gauge, and a computer. Output of the multi-channel amplifier (i.e. output of the five-force-sensors) and speech signals were digitized at a rate of 10 kHz and converted to 16 bits digital signals. The palatolingual contact stress was calculated from the output of the force sensor on the basis of relationship between the force applied to the protuberance of the force sensor and the output.

3. RESULTS

3.1 Static and dynamic characteristics of force sensor.

The force sensor mounted palatal plate was attached to a plaster cast of the hard palate and static and dynamic characteristics of the force sensor were investigated.

When the load applied to the protuberance of the force sensor increased from zero to 5gw at a 0.5gw interval and decreased to zero continuously, relationship between the applied

Table 1. Interference among force sensors.

in \ out	ch1	ch2	ch3	ch4	ch5
ch1	100	1.74	0.52	0.43	-0.09
ch2	4.92	100	3.24	1.04	-0.10
ch3	0.29	2.08	100	2.84	0.48
ch4	0.41	0.23	2.99	100	2.58
ch5	0.22	-0.62	1.32	5.44	100

stress and the output of the force sensor is shown in Figure 5. 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 of 0-62kPa was proportional to the stress applied to the fixed beam and had nearly no hysteresis. Measurement error of the force sensor was less than 2%.

For evaluating mechanical interferences among the force sensors, when a load of 10gw was applied to the protuberance of one force sensor, the output of the other force sensors were 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 in which output was measured. Outputs of the force sensor were normalized by the output of the force sensor to which the load was applied. Error by the mechanical interference among force sensors was less than 5.4%.

Dynamic characteristic of the force sensor was determined by the step response. When the load of 5gw that was applied to the protuberance of force sensor vanished instantaneously, response of the force sensor was measured. Results indicate that time Td for changing from the output of 90% level to 10% was 0.28ms.

The experiment for investigating the influence of the saliva on the static and dynamic characteristics of the force sensor

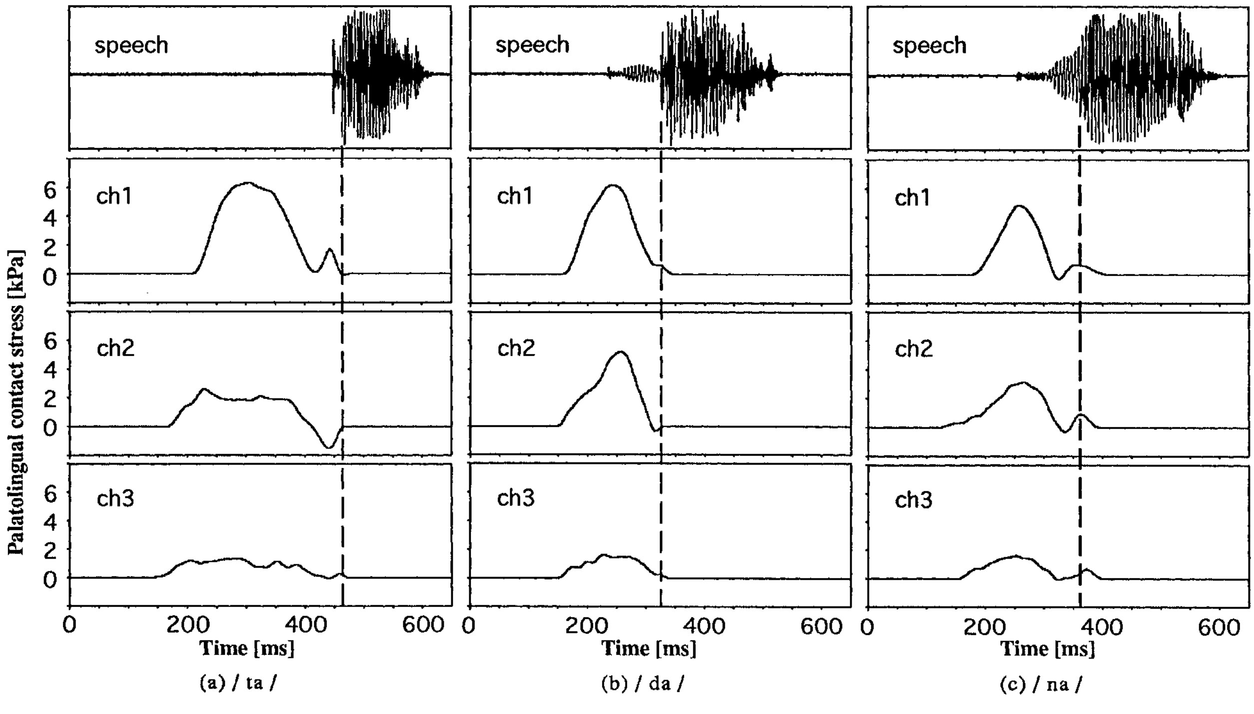

Figure 6 Time patterns of palatolingual contact stress during consonant productions.

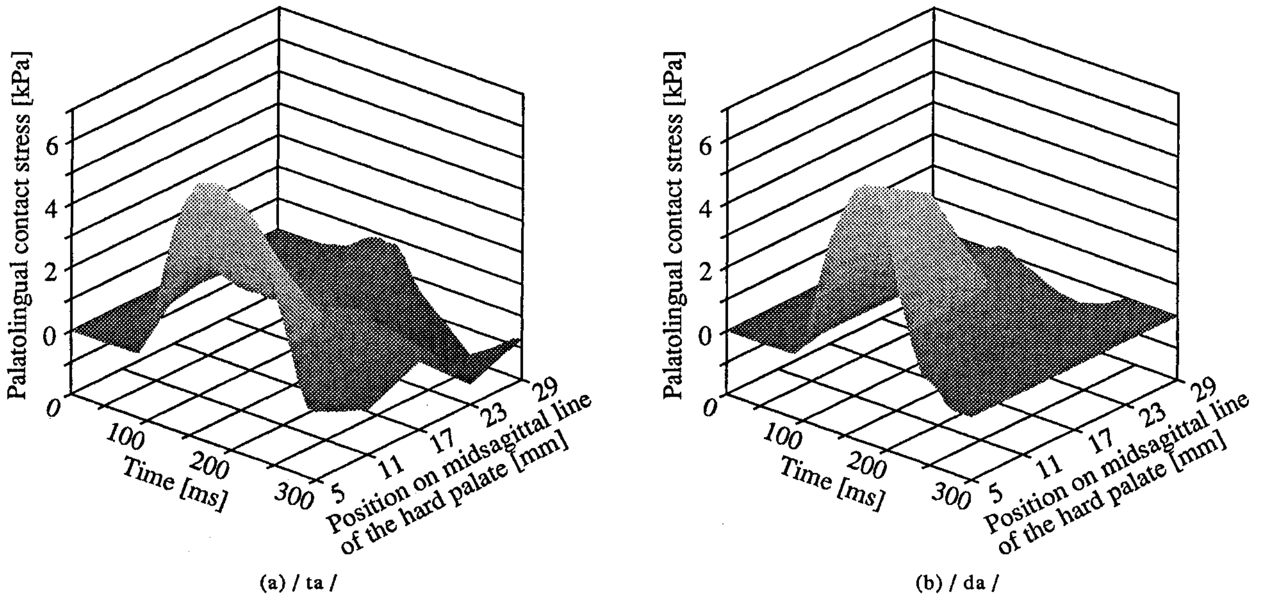

Figure 7 Three dimensional display of palatolingual contact stress and pattern in time-domain and space-domain.

was conducted. In a physiological saline solution (concentration of 0.9% and 0.6pH) which approximately have electrical and chemical properties of the saliva, the static characteristic of the force sensor was measured. As a result, in the physiological saline solution, The slope change of static (stress-output) characteristic was less than 3%. It can be considered that there is approximately no influence of the saliva on the static characteristics of the force sensor. Therefore, the static and dynamic characteristics of the force sensor appear quite adequate for studies of the palatolingual contact stress and pattern during consonant productions.

3.2 Measurements of palatolingual contact stress and pattern.

By means of this new system, a preliminary experiment for measuring the palatolingual contact stress and pattern in the mid-sagittal plane of the hard palate have been conducted.

The palatolingual contact stress and pattern of an adult male subject who has no history of speech disorder was measured during Japanese /CV/ (C=/t,d,n/ and V=/a,i,u,e,o/) productions. Each test word was uttered at a natural speaking rate. Outputs CH1, CH2, CH3, CH4 and CH5 of the force sensors indicate the palatolingual contact stress in the positions 5, 11, 17, 23 and 29mm from the dental ridge, respectively, along the midsagittal line of the hard palate. Because the force sensor mounted palatal plate is thin in thickness and is tightly attached to the hard palate, there was approximately no effect of the palatal plate in place on the speech production.

Figure 6 illustrates a typical time pattern of the palatolingual contact stress along with the audio signal in the productions of /ta/, /da/ and /na/. The output of the force sensors CH4 and CH5 which the tongue did not touch are not shown in the figure. The results show that (1) the maximum values of the palatolingual contact stress during the consonant productions were ranging from 5 to 6 kPa, (2) in the case of consonant /t/ production, when the palatolingual contact stress vanished, a burst was produced, and (3) the hard palate was oppressed by the surface of the tongue during /n/ production, and then, the palatolingual contact stress vanished when a following vowel was produced.

Figure 7 shows a three dimensional display in time-domain and space-domain of the palatolingual contact stress and pattern. The results indicate that the area of the palatolingual contact during /d/ production was larger than one during /t/ production. Therefore, by using the proposed system, dynamic aspect of the palatolingual contact stress in time-domain and space-domain were readily observed.

4. CONCLUSIONS

This study was performed to (1) develop a force sensor mounted palatal plate, (2) test its reliability, and (3) measure the palatolingual contact stress and pattern during consonant productions. As determined by the static and dynamic response data obtained, the force sensor mounted palatal plate possesses the performance properties required to detect the palatolingual contact and stress during consonant productions.

A prototype system which consists of a five-force-sensor mounted palatal plate, a multi-channel amplifier, and a computer has been developed. Using the proposed system, dynamic aspect of the palatolingual contact stress in time-domain and space-domain were readily observed during the productions of consonant /t/,/d/,/n/.

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