

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

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## 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