35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Measurement of Tongue-Artificial Nipple Contact Force in Infants with Sucking Difficulties

Eri Nishi, Yuki Wakamatsu, Yuiko Nagamatsu, Yuichi Kuroyanagi,
and Takuya Niikawa, *Member, IEEE*

Abstract— **Infants are known to suckle and ingest breast milk by wrapping the tongue around a nipple, writhing the tongue, and pressing the nipple. However, the dynamic mechanisms of tongue movement are still obscure, and factors related to sucking difficulties of infants are not well understood. We developed an artificial nipple installed with small cantilever-type sensors and directly measured the force applied on the nipple by the tongue. Small force sensors were arranged within the artificial nipple in a two-dimensional matrix of 3 × 2 to measure the force at 6 points. Subjects were 20 healthy infants (Group A) and 5 infants who had difficulty sucking (Group B). The latter could not breastfeed well and were fed from bottles or tubes. Informed consent was provided by the parents or guardians. The measured maximum force at the tip of the nipple was 1.4±0.4 N and 1.2±0.3 N (mean±SD) in Groups A and B, respectively. At the base of the nipple, the maximum force recorded was 0.8±0.5 N and 0.3±0.3 N (mean±SD), respectively, showing a statistically significant difference ($p<0.05$). The sucking period was 0.6±0.1 s (mean±SD) in both groups. The difference in time necessary to reach the maximum forces between the sensors at the tip and base was 39.7±28.8 ms (mean±SD) and 37.2±75.9 ms in Groups A and B, respectively.**

I. Introduction

The advancement of medical technologies has increased the survival rate of infants as well as the number of low birth weight (LBW) infants [1]. Many LBW infants have various difficulties requiring medical and engineering technologies for supporting sound growth. It is particularly important to solve difficulties related to nutrient intake which is critical for survival.

Infants are known to suckle and intake milk by wrapping the tongue around a nipple and writhing their tongues so as to press the nipple due to the sucking reflex. Studies on tongue movement of infants started about a half century ago by monitoring the sagittal plane by X ray [2]. Recently, tongue movement observations using safe ultrasonotomography [3][4] and small cameras [5] have been reported. To understand the dynamic actions of the tongue on the nipple, the pressure applied along the entire nipple or sucking pressure has been measured by using an ultra-small semiconductor pressure transducer [6] and a sucking pressure sensor [7]. However, the dynamic mechanisms of tongue movement are still obscure, and factors related to sucking difficulties of infants are not understood.

We developed an artificial nipple equipped with small cantilever-type sensors and directly measured the force applied on the nipple by the tongue [8] in order to analyze the dynamics of tongue movement during sucking.

In this study, tongue movements of 20 healthy infants and 5 infants with sucking difficulties were monitored using an artificial nipple installed with six small cantilever-type sensors, and the characteristics of the study groups were investigated. The output waveforms from the sensors showed that infants from both groups sucked about twice per second and produced cyclic signal waveforms that could be used to estimate the writhing movements of the tongue.

II. Tongue-Artificial Nipple Measuring System

2.1 Force sensors using strain gauges

The force sensors prepared for this study utilized a cantilever structure. A strain gauge was adhered to a thin stainless steel plate. The beam was deformed when a force was applied to an edge. Assigning the force applied to be F, strain as ε, and displacement as x, the relationship can be expressed as:

$$F = \varepsilon\, x \tag{1}$$

A sensor unit developed for this study is illustrated in Fig. 1. The beam was a thin plate of stainless steel 6.5 mm long, 2 mm wide and 0.3 mm thick. Wide-use foil strain gauges (KFR-2N-120-C1 Kyowa Electronic Instruments) were used. When the tongue touched the conduction block with a contact surface of 2 mm × 2 mm, the beam was distorted, and the resistance changed proportionally to the displacement. A bridge circuit was used to monitor the changes in resistance.

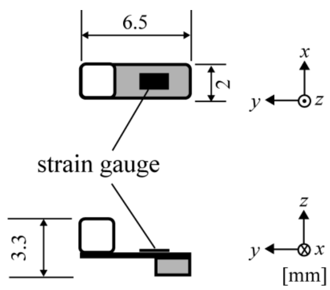
The sensors were arranged in three rows spaced 4.5 mm apart and two columns spaced 3.5 mm apart on a 70 mm long and 12 mm wide stainless steel plate and were installed in an artificial hollow elastomer nipple. A schematic illustration of the sensor unit in the oral cavity is shown in Fig. 2. Of the six force sensors (channels 1 to 6, hereinafter referred to as "ch"), chs. 1 and 4 were at the tip of the nipple, chs. 2 and 5 were in

E.Nishi is with Graduate School of Biomedical Engineering,Osaka Electro-Communication University, Osaka, Japan(e-mail: dl11a001@oecu.jp).
Y.Wakamatsu is with Graduate School of Biomedical Engineering,Osaka Electro-Communication University, Osaka,Japan(e-mail: ml12a015@oecu.jp).
Y.Kuroyanagi is with Department of Pediatrics,Osaka Koseinenkin Hospital Osaka,Japan (e-mail: yuichi.kuroyanagi@gmail.com).
Y.Nagamatsu is with Department of Pediatrics,Osaka Koseinenkin Hospital Osaka,Japan (e-mail: yuiko_honda@hotmail.com).
T.Niikawa is with Department of Biomedical Engineering, Osaka Electro –Communication University,Osaka,Japan(e-mail:taku@isc.osakac.ac.jp).

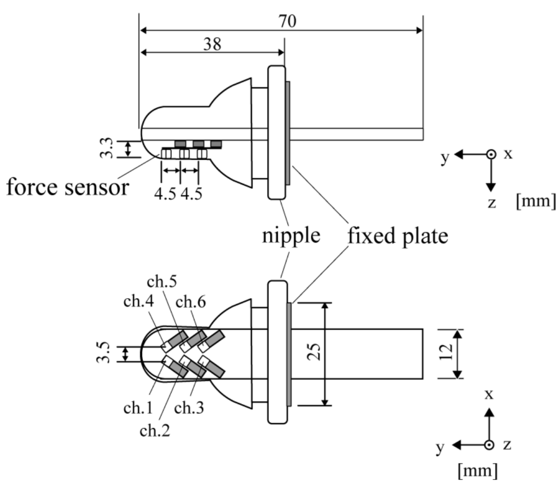
the middle, and chs. 3 and 6 were at the base. Therefore, chs. 1 and 4 touched the root of the tongue; chs. 3 and 6 touched the tip of the tongue.

2.2 *Properties of the force sensors*

The static and dynamic properties of the force sensors used in this study were assessed. The static characteristics were evaluated by increasing the load on the conduction block of the force sensor from 0 N to 3.92N in increments of 0.49 N, reducing the load to 0 N in decrements of 0.49 N, and measuring the output voltage. The outputs from ch.1 are shown in Fig. 3. All sensors showed linear increases up to the 3.92 N load , and the hysteresis was 1.0% to 4.4%.



(a) Cantilever force sensor



(b) Sensor unit

Fig. 1 Artificial nipple installed with small force sensors

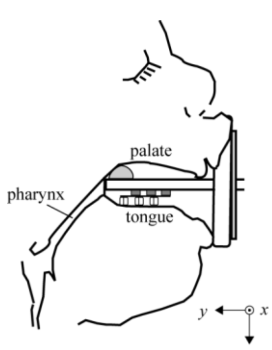


Fig. 2 Schematic illustration of the sensor unit in the oral cavity

The dynamic characteristics were assessed by applying a load of 3.92 N on the conduction block of an individual force sensor, removing the load, and measuring the response time. The output voltages from ch. 5 at the sampling frequency of 10 kHz are shown in Fig. 4. The output voltage decreased from 90% of the maximum to 10% in 0.5 ms to 1.8 ms across all sensors.

2.3 *System structure*

Signals from the sensors installed in the artificial nipple were amplified 1000 times and were transmitted to a personal computer via an analog-digital convertor with a USB connection. The quantization resolution of the convertor was 12 bit, and the sampling frequency was 100 Hz.

III. Measurement of Tongue-artificial Nipple Contact Force

3.1 *Measurement method*

Measurement was conducted by holding the infant and inserting the sensor unit in the oral cavity in the usual nursing position. As a positive offset component may be output while installing the artificial nipple, all signal offsets were removed

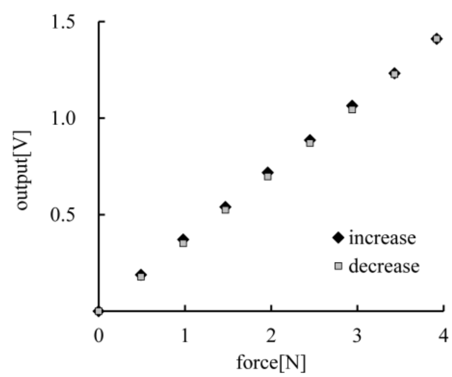


Fig. 3 Static characteristics of ch. 1

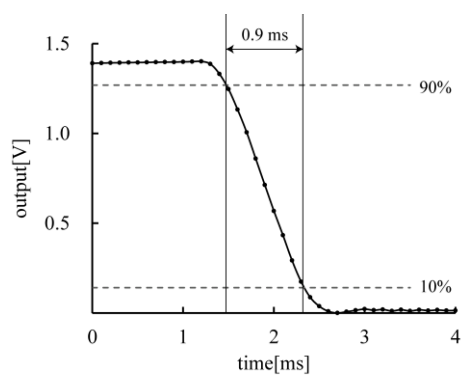


Fig. 4 Dynamic characteristics of ch. 5

before inserting the sensor unit in the oral cavity. The subjects were 20 healthy infants (Group A) and 5 infants who had sucking difficulties (Group B). The gestational age and birth weight of the healthy infants were 39.1±2.5 weeks (mean±SD) and 2889.4±651.8 g (mean±SD), respectively. The infants were 2 to 76 days old, the infants who had difficulty sucking were 3 to 20 days old, and their gestational age and birth weight were 38.2±1.5 weeks (mean±SD) and 3089.6 ± 536.6 g, respectively. The infants with difficulty sucking could not take in sufficient milk from the nipples of their mothers and were fed from feeding bottles or tubes. Informed consent was obtained from all parents or guardians.

3.2 Results of measurement

The output waveforms of an example Group A infant and an example Group B infant are shown in Figs. 5 and 6, respectively. Both groups showed periodic wave patterns with a sucking period of 0.6±0.1 s (mean±SD).

The mean of the maximum force in Groups A and B are shown in Fig. 7. The maximum force outputs at the tip of the nipple were 1.4±0.4 N (mean±SD) and 1.2±0.3 N in groups A and B, respectively. The values at the base of the nipple for groups A and B were 0.8 ± 0.5 N (mean ± SD) and 0.3 ± 0.3 N, respectively, showing a statistically significant difference ($p = 0.016$). In both groups, the maximum forces at the tip exceeded those at the base.

For each sensor, the time needed to reach the maximum force was calculated. The difference between the times to achieve maximum forces is shown in Fig. 8. Positive values denote that the tongue first touched the nipple at the base, and negative values denote that the tongue first touched the tip. The time difference between contacting the tip and base of the nipple was 39.7±28.8 ms (mean±SD) in Group A and 37.2±75.9 ms in Group B. (mean±SD), and no difference was observed except for the obvious difference in the sizes of the standard deviations.

IV. Discussion

Commonalities and differences were found between the healthy infants and infants with feeding difficulties. Both groups sucked the nipple about two times per second, showed periodic wave patterns, and stronger sucking force at the tip than at the base of the nipple. The maximum force at the tip of the nipple and the difference in time to reach the maximum force between the tip and base were also similar between the groups.

Different characteristics were observed between the groups in the maximum force at the base of the nipple and in consistency in the time difference between attaining the maximum force at the tip and the base of the nipple. The maximum force at the base of the nipple was significantly different between Groups A and B ($p<0.05$). The difference in time between contacting the tip and base of the nipple was more inconsistent in Group B than in A, showing regular peristalsis-like movement of the tongue in healthy infants from its equal variance ($p<0.01$). The time difference to reach maximum force between the tip and the root was observed in cycles of about 45 ms, but such regularity was not observed in the infants with difficulty sucking.

This study showed that infants who have difficulty

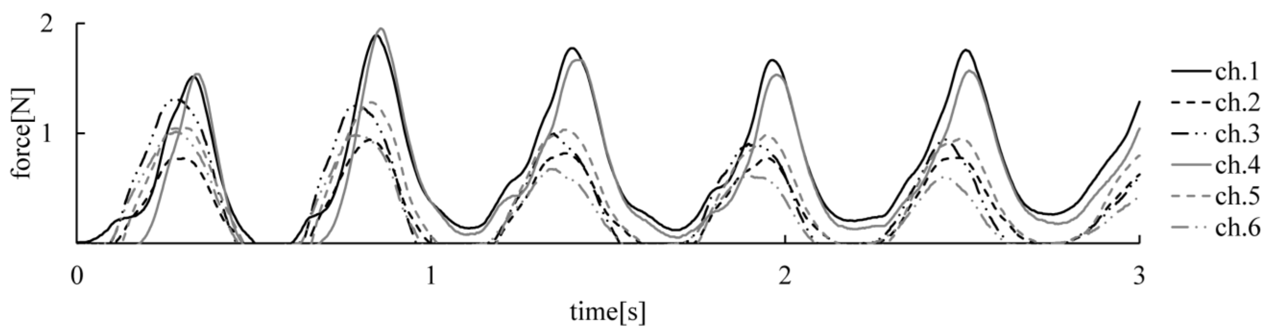


Fig. 5 Example output waveform of a healthy infant (Group A)

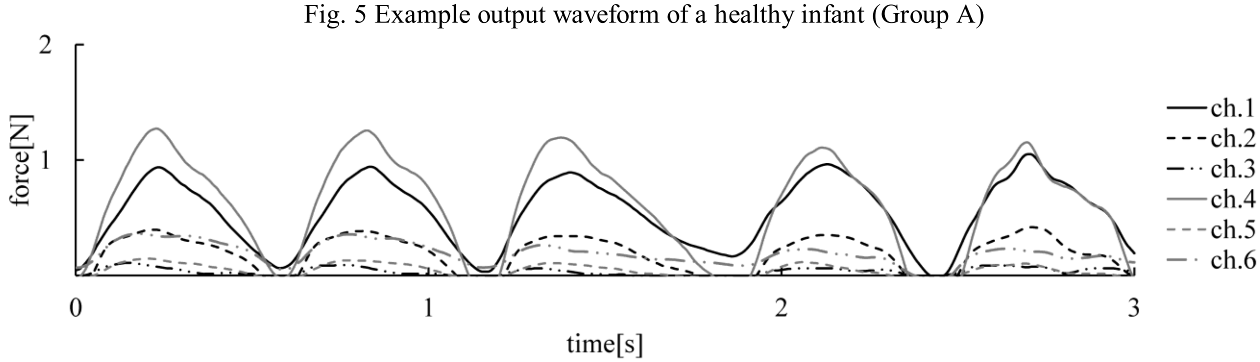


Fig. 6 Example output waveform of an infant with sucking difficulty (Group B)

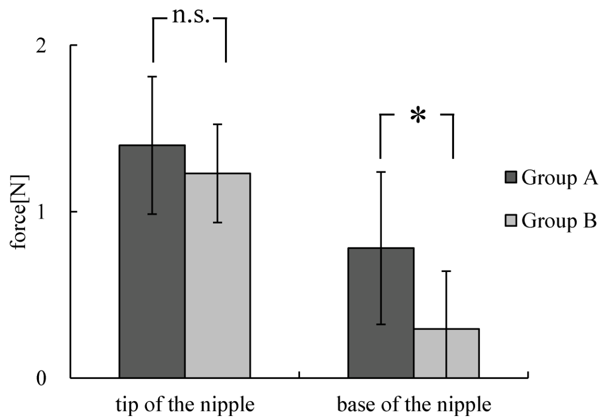


Fig. 7 Maximum forces per group at the tip and base of the nipple

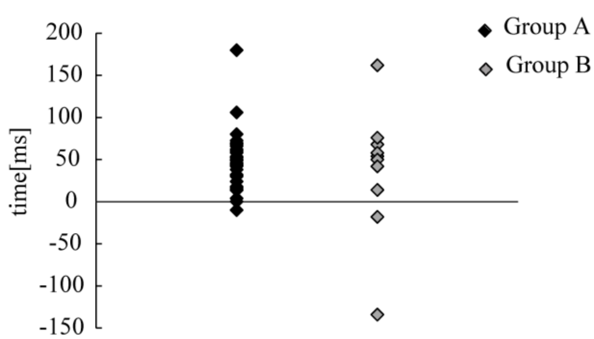


Fig. 8 Difference in time point of the maximum force value monitored by sensors between those at the base of the nipple and at the tip of the nipple

sucking are likely to have either or both of the following two problems. One is the force sensor installed at the root reached its maximum reading followed by the sensor installed at the tip of the tongue, resulting in both the tip and root of the tongue being in contact with the nipple at the same time. The other is insufficient force applied to the tip of the tongue although the peristalsis-like movement may be regular. Irregular writhing movement is likely to result in failure of squeezing the nipple. In the latter problem, the baby can squeeze the nipple, but the force at the tip of the tongue is too weak to extract milk. On the other hand, healthy infants are likely to support the nipple with the tip of the tongue, apply force sufficient for producing negative pressure, writhe the tongue with peristaltic movement from the tip to the root of the tongue, and suckle milk. For a baby to take in milk directly from the nipple of the mother, peristalsis-like movement of the tongue and force of about 0.8 N at the tip of the tongue are likely essential.

V. Conclusions

In this study, the movement of the tongue of 20 healthy infants and 5 infants who were diagnosed with sucking problems were monitored by using an artificial nipple equipped with six small sensors arranged in a matrix. The characteristics of the groups were compared.

The maximum force at the tip of the tongue was found to be very different between groups. Differences were also found in the consistency of time for the maximum force to move from the tip to the root of the tongue. These results allow quantification of tongue movement in the groups.

Takahashi [9] prepared an evaluation method for analyzing neonatal reflex patterns and movement patterns in healthy infants and infants with cerebral palsy for early detection of impairment in oral movement of infants. Early detection of cerebral palsy and early therapeutic exercise are believed to be effective for functional improvement. The measurement system used in this study can measure the sucking period, maximum sucking force, and the time difference in reaching maximum force between the sensors just by inserting the artificial nipple into the mouth of an infant and may be effective for early detection of such issues in clinics. Combining quantitative measurement of tongue movement with ultrasonotomography and other observations will enable detailed analysis of tongue movement in infants.

The experiments conducted in the study had the approval of the Osaka Koseinenkin Hospital Medical Ethics Committee. This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research(C), 22560431, 2010.

References

[1] T.Kondo, T.Ichihashi, H.Goto, K.Sugimoto, Y.Nakaoka, and Y.Tamura, "Characteristics of sucking and chewing function in extremely and very low birth-weight children ," The journal of Gifu Dental Society, Vol.30, pp.188-198. 2004.

[2] G. M. Ardran, F. H. Kemp, and J. Lind, "A cineradiographic study of bottle feeding ," Brit.J.Radiol, Vol.31, pp.11-22 . 1958.

[3] A. J. Nowak, W. L. Smith, and A. Erenberg, "Imaging Evaluation of Artificial Nipples during Bottle Feeding,"Arch.Pediatr.Adolesc.Med, Vol.148, No.1, pp.40-42. 1994.

[4] Y. Hayashi, K. Kanno, M.Seo, S. Kawasaki, S. Teramoto, R. Uehara, and Y. Eto, "Ultrasound Analysis of Sucking Behavior of Newborn Infants: Sucking Pressure of Newborn Infants with Cleft Palate during Nutritive Sucking," Jikeikai medical journal, Vol.49 , No.1, pp.47-49. 2002.

[5] K. Eishima, "The analysis of sucking behavior in newborn infants ," Early Human Development ,Vol.27, pp.163-173. 1991.

[6] M.Aizawa and K.Mizuno, "Measurement of Expression Pressure of Newborn Infants During Early Nutritive Sucking," The Journal of the Japan Pediatric Society, Vol.107, No.10, pp. 1352-1355. 2003.

[7] Y.Tamura, Y.Horikawa, T.Hayashi, and S.Yoshida, "Coordination of tongue movement observed through intraoral cammera and preioral muscle activity during suckling in infants," J.Jpn.Soc.Stomatognath Funct, Vol.2, No.1, pp.19-26. 1995.

[8] T.Niikawa, C.Hagino, E.Nishi, R.Kawachi, K.Minato, and Y.Takada, "Measurement of tongue-artificial nipple contact pressure during infant sucking," IEEJ Transactions on Electrical and Electronic Engineering, Vol.7, No.2, pp.190-196. 2012.

[9] H.Takahashi, "Evaluation Sheets on Oral Motor Dysfunctions in Young Infants," The Japan Journal of Logopedics and Phoniatrics, Vol. 26, pp.296-303. 1985.