

Application of Biological Gas Analysis toward Self-health Management

NTT DOCOMO is researching and developing self-health management using biological data in the health and medical care fields as part of its Smart Life vision. Many types of biological data reflecting individual differences can be obtained from biological gas contained in human breath and emitted from the skin's surface without the pain of drawing blood, and that data can be applied to self-health management through multi-item analysis. We have developed devices that measure a variety of biological gas components contained in breath or emitted from the skin's surface on the sole of the foot for use as markers of fat metabolism, alcohol intoxication, and other conditions. These easy-to-use devices are expected to be useful in maintaining and improving one's health and in the prevention and early detection of disease.

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1. Introduction

In April 2015, NTT DOCOMO announced “New Initiatives toward Delivery of Medium-term Targets” with a focus on value generation through co-creation with diverse partners and solutions to social issues through services [1]. These social issues include those in the health and medical care fields, so R&D at NTT DOCOMO aims to solve issues arising in the various stages of life such as lifestyle-related diseases and to

contribute to healthy and long lives. Important issues here include the prevention of diabetes, hypertension syndrome, and other conditions occurring during pregnancy and the alleviation and prevention of lifestyle-related diseases in adulthood (**Figure 1**).

With respect to the former, NTT DOCOMO is conducting joint research with Tohoku University with the aim of establishing methods for the prevention and early detection of pregnancy-related diseases through information analysis. In addition

to the use of genome information^{*1}, this research will combine data related to periodically obtained biological substances from blood samples, etc. and healthcare data obtained daily using a healthcare data collection platform^{*2} [2] [3].

With respect to the latter, NTT DOCOMO has undertaken the visualization of fat metabolism with the aim of alleviating and preventing obesity, which can lead to all sorts of diseases and raise the risk of acquiring lifestyle-related diseases. Specifically, we have come to develop

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^{*1} **Genome information:** Information related to the various types of genes possessed by living organisms.

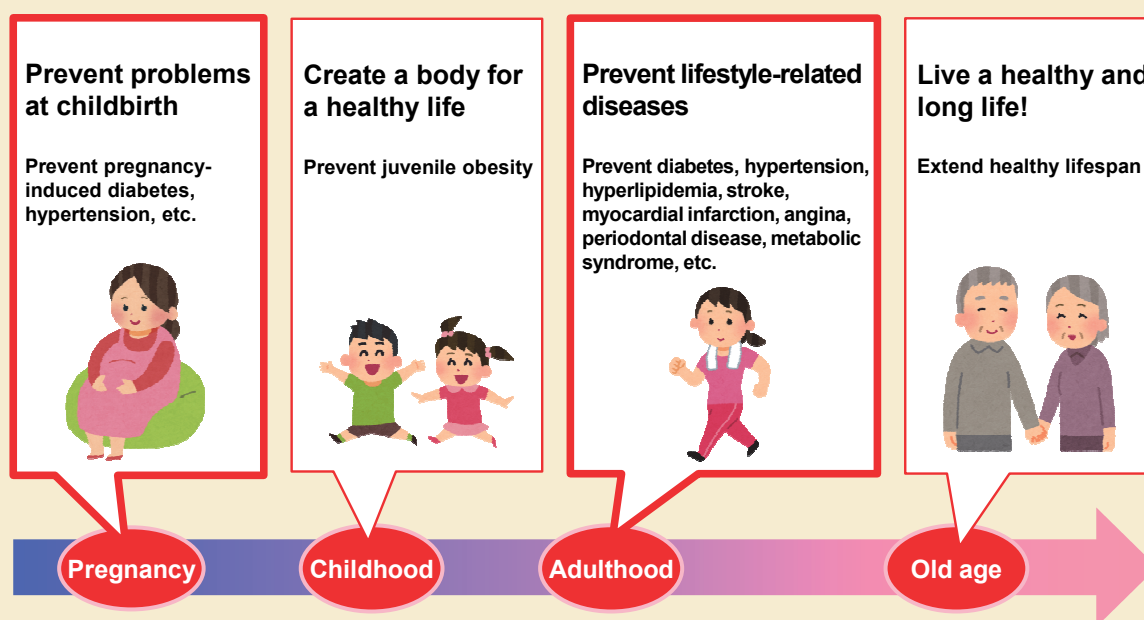


Figure 1 NTT DOCOMO's medium-term vision in health and medical care fields

breath analyzers [4] [5] and arm-wearable monitors [6] [7] for measuring acetone^{*3}, a marker of fat metabolism. Biological gases^{*4} like acetone contained in breath or emitted from the skin's surface can provide abundant biological data on metabolic processes reflecting individual differences without the pain of drawing blood, and the use of such devices requires no special qualifications in collecting or analyzing samples. There are therefore high expectations for applying biological gases to self-health management through trouble-free multi-item analysis that can be performed inside or outside the home.

Against the above background, NTT DOCOMO has installed a breath

analyzer in a health kiosk developed as an application of self-health examinations outside the home and developed a skin gas^{*5} analyzer targeting gas emitted from the sole of the foot as an application of self-health management in the home. These user-friendly devices are expected to be useful in maintaining and improving one's health and in the prevention and early detection of disease. This article provides an overview of these newly developed devices.

2. Installation of Breath Analyzer in Health Kiosk

2.1 Overview of Health Kiosk

A "health kiosk" is a piece of equipment that enables the user to check for

health problems by activating a variety of sensors and health management devices installed in the kiosk while following directions on a screen. This kiosk, which was developed and manufactured by Smart Service Technologies Co., Ltd. under the guidance of the Experimental Center for Social System Technologies (Fukuoka Industry, Science & Technology Foundation) and System LSI Research Center, Kyushu University, is capable of performing more than 21 types of self-health examinations including height, weight, blood pressure, body fat percentage, body temperature, pulse, visual acuity, hearing acuity, lung capacity, glaucoma, cataracts, electrocardiogram, mental health,

^{*2} **Healthcare data collection platform:** A platform designed for collecting routinely measured healthcare data such as blood pressure and amount of physical activity and for determining some of that person's lifestyle practices with high accuracy and high frequency.

^{*3} **Acetone:** A highly volatile organic compound—chemical formula: C_3H_6O .

^{*4} **Biological gases:** Gases contained in breath or emitted from the surface of the skin.

^{*5} **Skin gas:** Biological gas emitted from the surface of the skin.

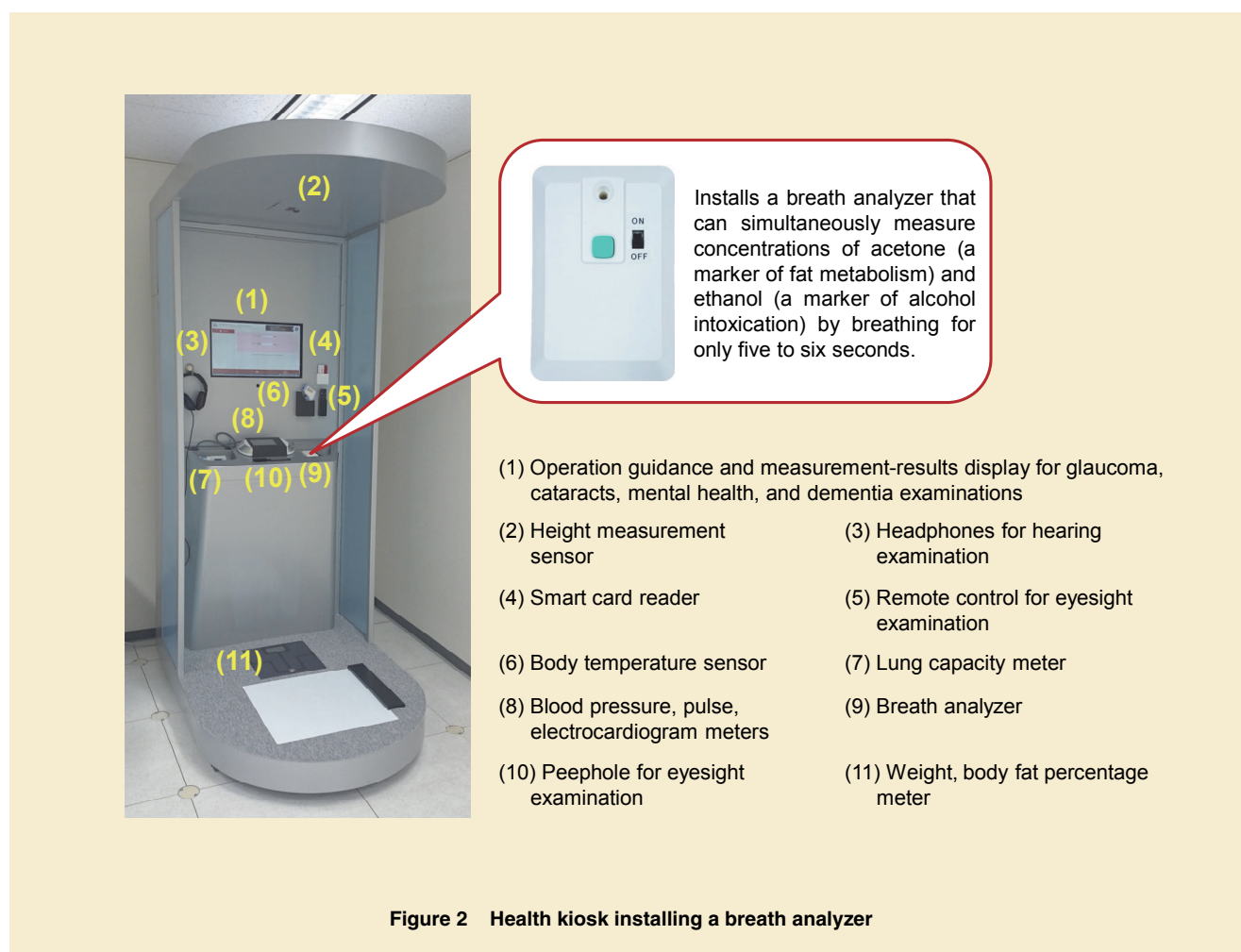
and dementia (**Figure 2**). After a personal authentication process by smart card, the kiosk displays the results of each examination on the screen for the user to view while also storing them on a network server. The user can review these stored results later on a personal computer or mobile terminal.

2.2 Installation of Breath Analyzer

Human breath includes several hundred types of gas components in addition to acetone, and some of those components

can give rise to errors in acetone measurement. For this reason, conventional gas analyzers separate gas components before performing measurements, but this scheme tends to enlarge the size of the equipment. To resolve this issue, the breath analyzer developed by NTT DOCOMO incorporates two types of semiconductor-type gas sensors having different sensitivity characteristics. For the first gas sensor, we selected tungsten oxide as the main sensor material because of its exceptionally high sensitivity to acetone. Then, for the second sensor, we

selected tin oxide as a main sensor material because of its sensitivity to acetone and gas components that give rise to errors in acetone measurement. Next, we performed beforehand a sensitivity-characteristic evaluation of these semiconductor gas sensors with respect to acetone and gas components that give rise to errors in acetone measurement and determined a calibration curve^{*6} for each of the results obtained. Finally, we recorded these curves in the developed breath analyzer making it possible to calculate the concentration of acetone



^{*6} **Calibration curve:** A curve that shows the relationship between standardized substances whose amounts and concentrations are known and measured data.

in breath with good accuracy without having to separate gas components. As a result, we succeeded in developing a compact and light breath analyzer with dimensions of $65 \times 100 \times 25$ mm and a weight of 125 g, which is approximately 1/100 the volume and 1/50 the weight of conventional breath analyzers that perform rigorous gas analysis by separating gas components.

In addition to having a compact and light configuration, NTT DOCOMO's breath analyzer is also easy to operate. These features make for easy installation in a health kiosk enabling the provision of a function for examining fat metabolism. The addition of this breath analyzer has made this health kiosk the world's most advanced self-health examination device for determining the presence of metabolic disorders brought on by diabetes, eating disorders, and excessive diets.

This health kiosk is expected to be useful in determining the need for consultation at a clinic or hospital, for improving one's health, and for early detection of disease, and it should be particularly useful in regions having a shortage of physicians, on remote islands, etc. Going forward, the plan is to conduct usage experiments both inside and outside Japan targeting the residents of such areas with the aim of assessing the effectiveness of this health kiosk. We would also like to see this health kiosk installed in public facilities, drug stores, and other establishments outside the

home to make it easy for people to perform self-health examinations.

3. Development of Foot-sole Skin Gas Analyzer

3.1 Overview of Analyzer

Daily measuring of one's weight has become a widespread practice for managing weight and dieting and has therefore become an important means of alleviating and preventing obesity. The functional performance of weight scales and body composition analyzers has been advancing in recent years, and devices that can measure not only weight and body fat percentage but also muscle mass, bone mass, and other physical characteristics have become commercially available. It would be no exaggeration to say that at least one weight scale or body composition analyzer can now be found in each home. In short, the weight scale or body composition analyzer is a typical healthcare device that has gained widespread acceptance in society.

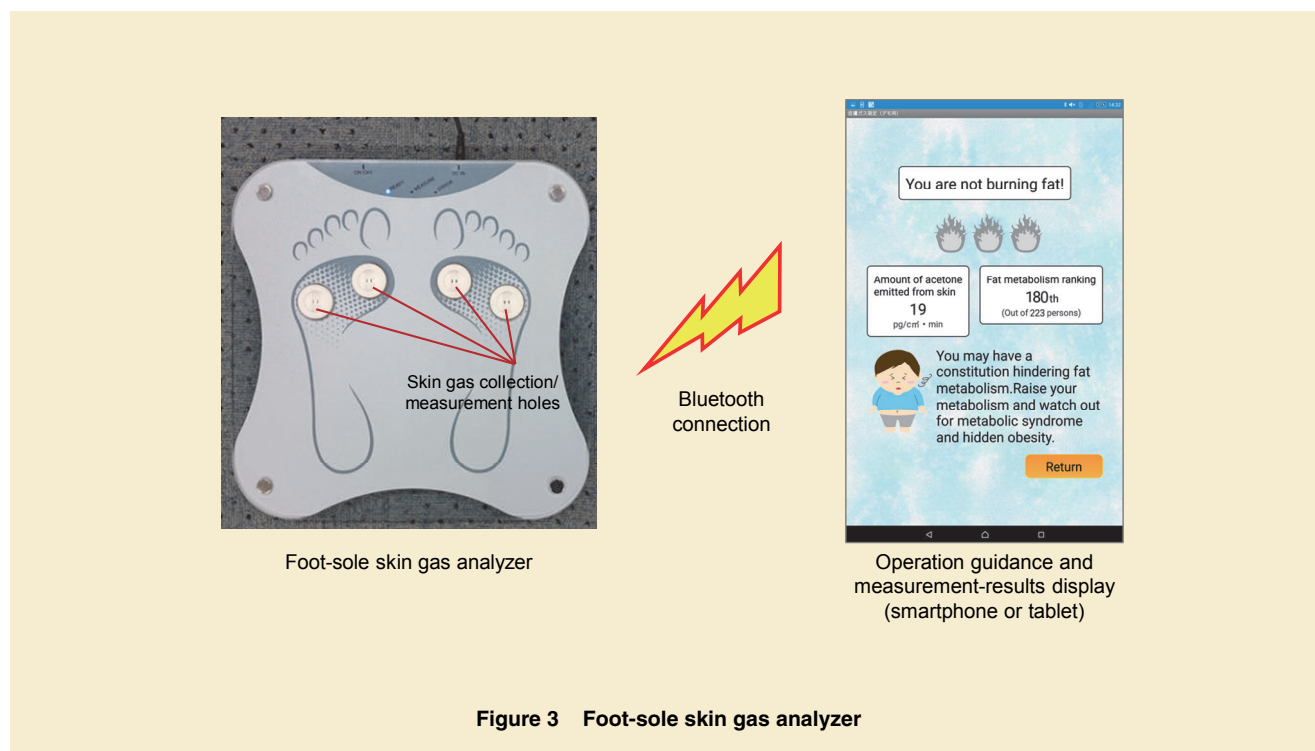
Biological gas components such as acetone, ethanol^{*7}, and water vapor that act as markers of fat metabolism, alcohol intoxication, and dehydration, respectively, are not only contained in human breath but also emitted from the surface of the skin. Consequently, if skin gas components like acetone can be measured at the same time as weight measurement, it should be possible to perform a multi-item health check in a hassle-free

manner. To this end, NTT DOCOMO has developed the world's first "foot-sole skin gas analyzer" that can simultaneously measure the three gas components of acetone, ethanol, and water vapor by having the user simply stand on a device patterned on a weight scale (Figure 3) [8].

The developed device has dimensions of $30 \times 30 \times 3.5$ cm and a weight of 1.7 kg, which is comparable in size and weight with popular weight scales and body composition analyzers. It features four holes for skin-gas collection and measurement, each of which is equipped with a gas sensor highly sensitive to acetone, a gas sensor highly sensitive to ethanol, and temperature/humidity sensors as well as a physical switch for determining that the user has stepped onto the device. Since the amounts of gas components emitted from the skin are much smaller than those of gas components contained in breath, measures were taken to enable the measurement of minute levels of skin gas components such as increasing the sensitivity of the gas sensors themselves and using appropriate methods for installing the gas sensors in the device. After the user steps onto the device, it takes approximately 20 seconds to simultaneously measure the acetone, ethanol, and water vapor emitted from the soles of the feet. In addition, while the molecules of biological gas components like acetone are about several angstroms (Å)^{*8} in size, the fiber of socks or stockings has a mesh

^{*7} **Ethanol:** A highly volatile organic compound and the main component of alcoholic beverages—chemical formula: C_2H_6O .

^{*8} **Å:** A unit of length equal to 10 billionth of a meter.



approximately several hundred μm ^{*9} in size, which is large enough for those molecules to pass through. In other words, the device is capable of measuring biological gas components even if the user is wearing socks or stockings. Measurement results are transmitted to the user's smartphone or tablet by wireless transmission using Bluetooth[®]*10.

An Android[™]*11 application has been developed for installation in the user's smartphone or tablet. This application receives the measurement results transmitted by the device and visually represents the user's current level of fat metabolism, alcohol intoxication status, dehydration status, and health-related advice by a Graphical User Interface (GUI)*12. Typical screenshots of this application showing measurement results

are shown in **Figure 4**.

3.2 Performance Evaluation Experiment

We conducted a performance evaluation experiment to assess measurement accuracy by the gas sensors installed in the developed device. Specifically, we measured acetone and ethanol emitted from the skin of several subjects using the developed device and conventional large-size gas measuring equipment (gas chromatography equipment*13) and compared the amounts of each gas component between both types of equipment. This experiment revealed that measurement results by the developed device and measurement results by conventional large-size equipment showed high positive correlation (acetone correlation

coefficient*14 $R = 0.87$, ethanol correlation coefficient $R = 0.99$) (**Figure 5**). These results show that the performance of the developed device is practical enough for determining one's health status at home in an easy-to-use manner. At present, the developed device can only measure three types of skin gas components, but the plan is to implement more functions for measuring body weight, etc.

3.3 Expected Effects

1) Dieting Support and Health Advice

Successful dieting requires a decrease not in water or muscle but in body fat, but measuring only body weight is not enough to determine whether that reduction in weight is in body fat or water/muscle. In contrast, acetone is a metabolic

*9 μm : A unit of length equal to 1 millionth of a meter.

*10 **Bluetooth[®]**: A short-range wireless communication standard (IEEE 802.15.1) using the 2.4 GHz band and requiring no registration or licensing for use. A registered trademark of Bluetooth

SIG, Inc. in the United States.

*11 **Android[™]**: A Linux-based open source platform developed by Google Inc. in the United States targeting mainly mobile information terminals. A trademark or registered trademark of Google Inc. in the United States.

*12 **GUI**: An interface that represents operations and objects graphically on a screen and that excels in intuitive operability and visibility.

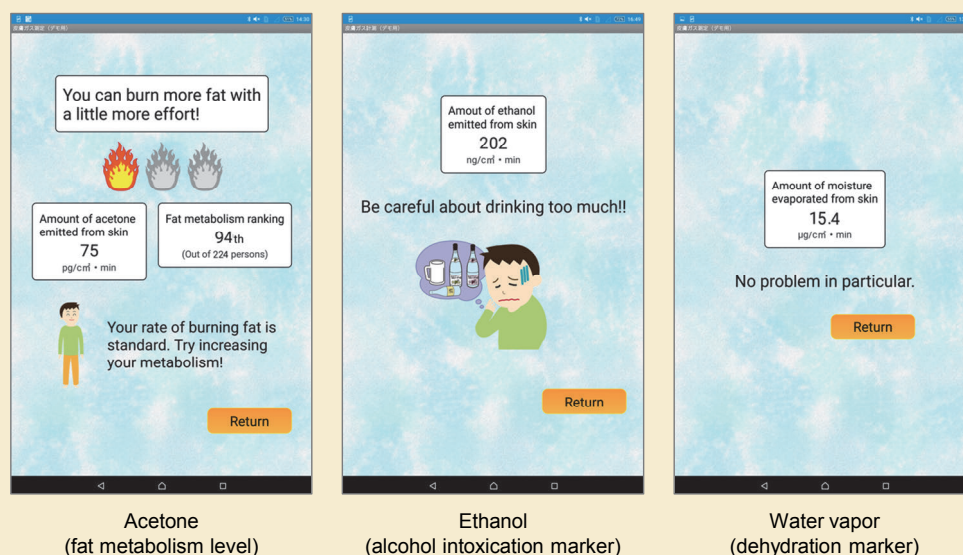


Figure 4 Screenshots of measurement results

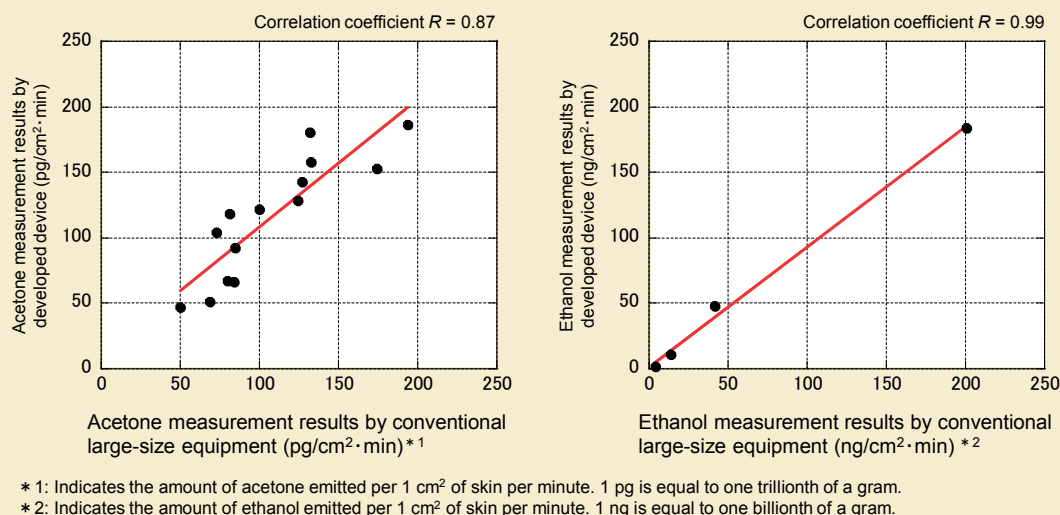


Figure 5 Comparison of acetone/ethanol measurement results

product emitted in conjunction with the decomposition and metabolism of body fat, so measuring it together with body

weight makes it possible to determine whether any reduction in weight is due to a decrease in body fat. This scheme

supports effective dieting. In addition, a body composition analyzer based on the impedance method^{*15} can suffer from

***13 Gas chromatography equipment:** Micro-analysis equipment generally used for identifying and quantifying gas components by using a column to separate and measure them.

***14 Correlation coefficient:** A statistical index indicating the degree of similarity between two

variables. The closer to 1 this value is, the more similar the variables, while the closer to 0, the more dissimilar.

***15 Impedance method:** A method for indirectly determining water volume, body fat percentage, and muscle mass by passing a weak current through the body and measuring electrical conductance.

large measurement error due to the effect that an increase or decrease in the amount of body water can have on the measurement of body fat, but that effect is not present in acetone measurements. In this regard, excessive dieting can lead to an inadequate intake of carbohydrates, which can produce excessive decomposition and metabolism of body fat and result in an abnormally large amount of emitted acetone. Calling attention to this condition can prevent harm to the user's health. For people interested in dieting, stepping on a weight scale is a daily activity, so evaluating fat metabolism by acetone measurement incurs no burden. Finally, the results of measuring ethanol and water vapor can be used to estimate lifestyle-related habits such as the frequency of drinking alcohol and offer health-related advice.

2) Early Detection of Ketoacidosis

Measuring acetone is expected to be useful in the early detection of a metabolic disorder (ketoacidosis) in diabetic patients and pregnant women. Ketoacidosis indicates a state in which the blood becomes acidic due to a buildup of ketone bodies^{*16}. It is known to be a condition in which failure to receive appropriate and early treatment can lead to death. There is also the risk that symptoms can become even more serious in a state of dehydration. Since diabetic patients and pregnant women manage their weight on a daily basis, measuring skin gas components together with weight increases the possibility of detecting the

onset of ketoacidosis early without having to perform any burdensome tasks.

4. Conclusion

In this article, we overviewed a health kiosk incorporating a breath analyzer as an application of self-health examinations outside the home and a skin gas analyzer targeting gas emitted from the sole of the foot as an application of self-health management at home. By making these devices easy to use on a routine basis, we expect them to be useful in maintaining and improving a person's health and in the prevention and early detection of disease.

In Japan, the difference between average lifespan and healthy lifespan^{*17} is 9.13 years for men and 12.68 years for women as of 2010, which indicates that there is an unhealthy period that limits everyday life lasting from about 9 to 13 years [9]. In addition, a comparison of data between 2001 and 2010 reveals that average lifespan in Japan increased by 1.48 years for men and 1.37 years for women while healthy lifespan increased by only 1.02 years for men and 0.97 years for women. That is to say, the increase in healthy lifespan was smaller than the increase in average lifespan [9]. Both of these differences are expected to escalate in the years to come, which means that the unhealthy period that consumes considerable healthcare and nursing-care benefits will be increasing. This is another reason why extending the healthy lifespan

is necessary.

NTT DOCOMO seeks to contribute to solutions for social issues through various R&D initiatives in the health and medical care fields such as extending the healthy lifespan to shorten its difference with the average lifespan.

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^{*16} **Ketone bodies:** Generic name for acetone, acetoacetic acid, and beta-hydroxybutyrate.

^{*17} **Healthy lifespan:** The period in which a person can go about his or her daily life in a state with no health problems.

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