

Relationship between BrACs and BACs of Healthy Koreans for BAIIDs

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Abstract

This study aims to suggest the partition ratio (Q-factor) of healthy Koreans and the comparison results of breath alcohol concentration (BAC) measurements using two methods (photoacoustic and electrochemical methods) for developing breath alcohol ignition interlock devices (BAIIDs). Given the relationship between BACs and BrACs and the Q-factor, the alcohol metabolism of healthy Koreans (96 males and 91 females) is revealed for understanding the digestion of alcohol and surveying the fundamental data of alcohol-related problems, CO₂ concentrations vs. alcohol concentrations, and the performance of alcohol sensors in the marketplace. The average Q-factor of healthy Korean males and females are 1,913 (95% confidence interval from 1,889–1,937) and 1,991 (95% confidence interval from 1,945–2,036). Photoacoustic measurements could be applied to predict the BACs of drinkers, which is confirmed by the Bland–Altman plots presented in this study. The biases based on the partition ratios (Q=1,913 and Q=1,991) in the Bland–Altman plots were -0.0004% (95% CI from -0.0011 to +0.0003% for males) and -0.0017% (95% CI from -0.020 to +0.017% for females).

Keywords: Breath alcohol concentrations, Blood alcohol concentrations, Partition ratio (Q-factor), CO₂ concentration in breath, Photoacoustic methods

1. INTRODUCTION

Vehicles are becoming increasingly important for travel, commuting, logistics, etc. However, as the number of automobiles has increased, road traffic safety has become a worldwide problem for reducing road traffic accidents and fatalities. Sweden declared a Vision Zero slogan to eliminate any victims from road traffic accidents [1]. Among road traffic accidents, alcohol-related accidents and fatalities are primary concerns worldwide in terms of improving safety in road traffic situations. To alleviate alcohol-related accidents, most nations use alcohol sensing apparatus for screening drunken drivers, which measures BrAC using optical components or fuel-cell type devices [2-4].

Currently, breathalyzers for monitoring BrAC are widely used to screen impaired drivers at roadsides. The legal limit for

impairment is 0.08% in the U.S. and 0.05% in most European countries. Although Sweden adopted a 0.05% BAC limit in the 1950s, the legal BAC limit was recently lowered to 0.02% to further improve traffic safety. James and Robert reported that fatal crashes and severe personal injuries have decreased by lowering legal limits, leading to safer road traffic situations [5]. In 1962, the Korean government legitimized road traffic laws to enforce alcohol-impaired driving. Four decades later, BrAC analysis for road traffic offences was regulated in 2006, with a legal BAC limit of 0.05% for driving. In addition, several trials have been conducted to decrease the legal limit of BAC to 0.03% for road traffic safety and reduce alcohol-related fatalities. Finally, the Korean government settled its legal limit to 0.03% in 2019.

Because consumed alcohol is eliminated from the body through the exhaled air that comes from the deep lungs [6,7], the measurement of BrAC has been used to analyze BAC for decades. The relationship between BAC and BrAC has been studied for a long time; therefore, BAC is currently converted from BrAC by multiplying with the ratio of BAC to BrAC, known as the partition ratio or conversion factor, Q. The US National Highway Traffic Safety Administration (NHTSA) uses a Q-factor of 2,100 [8], which was also adopted for converting BrAC to BAC in Korea. However, Jones and Andersson reported that most countries adopt a conversion factor of 2,000–2,300 [9]. Furthermore, a recent study showed that the conversion factor could range from 2,225 to 2,650; Jones and Andersson reported an

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average conversion factor of 2,448 in their article [10]. Pavlic et al. presented the time dependency of Q ranging from 2,225 to 2,650 [11]. Lindberg et al. showed that the BAC/BrAC ratio was 2,251 in Swedish subjects [1].

The Q-factor is relevant to the BAC determined by the breathalyzer and varies from country to country. Therefore, the primary objective of this study is to identify the BAC/BrAC ratio of healthy Koreans and identify alternative BAC measurement methods to estimate BACs and screen drunken drivers correctly.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1 Subjects

Healthy Koreans (96 males and 91 women) with ages ranging from 20 to 50 years were enrolled in this study as paid volunteers. None of the subjects were heavy consumers of alcoholic beverages (less than two bottles of soju (20% (v/v) in their regular lifestyle). This study was approved by the Ethics Committee of the Konkuk University Hospital, Korea.

2.2 Experimental procedures

Volunteers were recruited by posting announcements through the Internet or public boards. The volunteers were screened by a psychiatric doctor through basic medical and psychiatric checkups, including physical examination, vital signs, complete blood count (CBC), and liver function test (LFT), Alcohol Use Disorder Identification Test-Korea (AUDIT-K) and cut-down, annoyance, guilt, eye-opener (CAGE) surveys. Finally, 187 individuals were selected to participate in the study. Since it took approximately 2 min to analyze one breath sample, the male and female volunteers were divided into ten groups. The volunteers that belonged to each sub-group were randomly selected, and each subject was asked to consume 0.35 mg/ml/kg or 0.7 mg/ml/kg Soju (30% (v/v)) for 15 minutes. After consuming alcohol, they were allowed to rinse their mouth with drinking water to ensure the absence of mouth alcohol before the first test; however, they were not allowed to drink water until 2 h after consuming the alcohol. The samples (one blood and two breaths) were obtained at timed intervals of 15, 30, 45, 60, 90, 120, 180, and 240 min after drinking alcohol to reveal the relationship between BAC and BrAC in healthy Koreans. To avoid complexity in subsequent data interpretation, no food or mixing of different alcohols was

allowed. Furthermore, strenuous physical activity was not allowed during the experiment.

2.3 Collection of blood and BAC analysis

After drinking alcohol mentioned earlier, a blood sample (2 mL) was drawn from the proximal stopcock, which was connected to the indwelling catheter at each timed interval, as mentioned earlier, and injected into a 3 mL Vacutainer tube (BD Franklin, Lake NJ, USA) containing Ethylenediaminetetraacetic acid (EDTA). The tubes were stored in a refrigerator at 4 to 6 °C and brought to the Neodin Medical Institute, Seoul, when the experiments were completed for each sub-group. Each delivered blood sample was analyzed by enzymatic methods (COBAS Integra 800, Roche, USA) twice to reveal the BACs.

2.4 BrAC measurements

One breath sample from each volunteer was collected with 3-liter non-odor bag (TK005-N-003, BMS Corp., Japan) and analyzed using a multi-gas analyzer (INNOVA-1312, LumaSense Technologies, Denmark). The analyzer used in this study comprised two main components: optical and acoustic measurement units. By adopting photoacoustic measurement principles, gases can be analyzed at the ppb to ppm levels. Therefore, this analyzer was selected as the reference BrAC measurement apparatus in this study. However, to enhance measurement reliability, the multi-gas analyzer was sent back to the manufacturer to add a new filter (for ethanol measurement) and was calibrated to ensure measurement accuracy. After measuring each breath sample three times using a multi-gas analyzer, the average BAC was converted to a percentage by multiplying with the conversion factors. The other breath samples for each person were measured using four portable breathalyzers (AL9000, Sentech Corp., Korea) at timed intervals of 15, 30, 45, 60, 90, 120, 180, and 240 min after drinking alcohol. The four measured values were then averaged after finishing the tests for comparison. Each portable breathalyzer was calibrated before the experiments to alleviate the reliability problems raised in the fuel cell-type breathalyzer.

2.5 Calculation of Q-factor

The partition ratio Q was individually calculated for each subject from the ratio of the mean BAC value to the average BrAC value determined by the multi-gas analyzer. However, the

ratio of BAC to BrAC value, the Q-factor, is assumed to be 2,100 in portable breathalyzers because the Korean jurisdiction established the value recently. All statistical parameters, such as average, standard deviations of average, and 95% confidence intervals for the calculated parameters, were acquired using MS Excel and Sigma Plot 12.5 also.

3. RESULTS AND DISCUSSIONS

Arranging the results of BACs according to the elapsed times, healthy Korean women also show three characteristic alcohol metabolism patterns as shown in Fig. 1: early-saturation, saturation, and non-saturation patterns. It is quite similar to the results of Korean males reported previously[12]. As can be seen in Table 1, Korean women show around 44% of non-saturation pattern. It means that Korean women digest the alcohol more easily than the males. As suggested in Fig. 1 and Table 1, the alcohol metabolism of Korean adults could be confirmed with three characteristic patterns.

Fig. 2 shows the relationship between BACs and BrACs measured using two different apparatuses: a multi-gas analyzer and a portable breathalyzer with an assumed partition ratio $Q=2,100$. In the case of Korean males and women, BACs were overestimated using the multigas analyzer, as depicted in Fig. 2; regression lines $y=1.032x+0.0042$ with $R^2=0.849$ for males and $y=1.003x+0.0047$ with $R^2=0.892$ for women. However, when breath alcohol concentrations were measured with a portable breathalyzer, the BACs were underestimated, as shown in Fig. 2; regression lines $y=0.749x-0.0007$ with $R^2=0.802$ for males and $y=0.7885x+0.0001$ with $R^2=0.859$ for females. From the BACs and BrAC analyses, the partition ratio should be lowered in a multi-gas analyzer and increased in a portable breathalyzer for correct BAC measurements.

Although the results of the multi-gas analyzer were similar to the blood alcohol concentrations for all subjects, the BrACs and BACs results did not exactly match in both measurement methods, as shown in Fig. 1 and Fig. 2. A small bias of approximately 10% of the error ($\pm 0.005\%$) exists with the measurement of the multi-gas analyzer; however, the data measured by the breathalyzer showed a slightly higher offset value in the BAC measurements. Furthermore, although the BACs had meaningful values, the breathalyzer didn't monitor the actual BACs in some subjects. Therefore, the partition ratio was calculated according to the sex, elapsed time, and the average value at all time intervals.

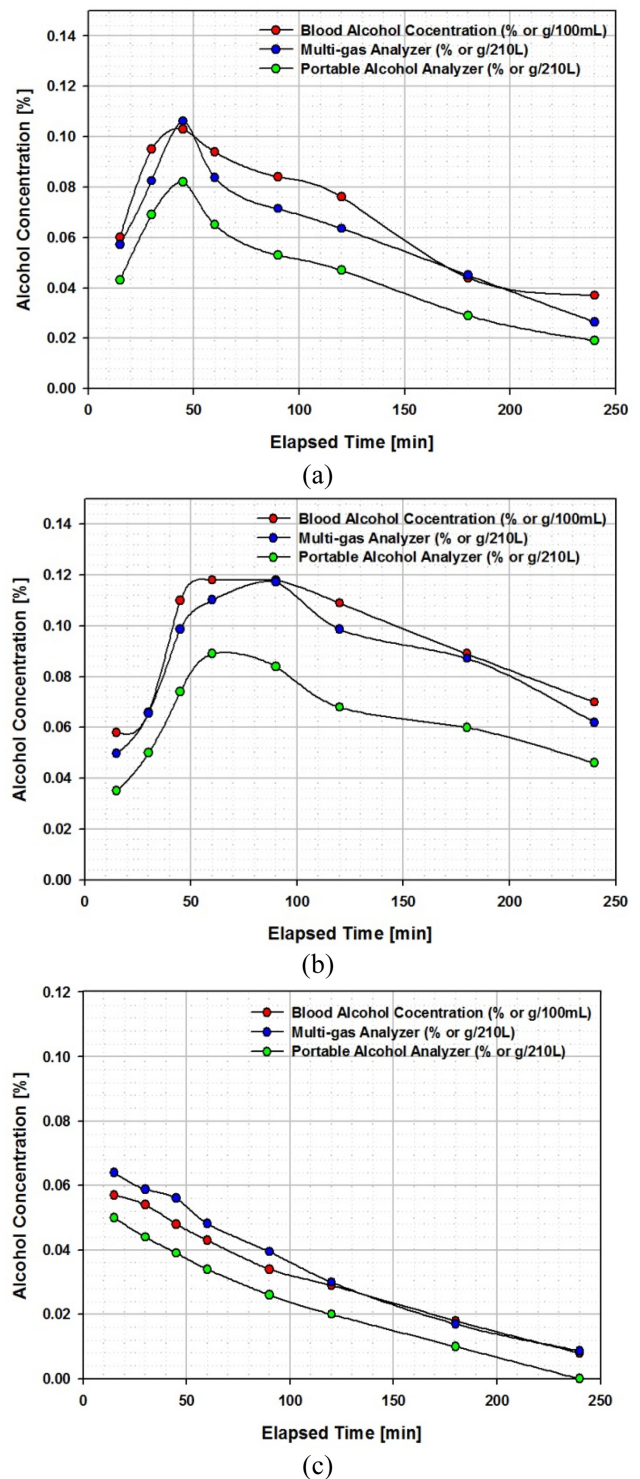


Fig. 1. Three characteristic patterns of BACs: (a) early saturation, (b) saturation, (c) non-saturation.

Table 1. The ratio of three different alcohol metabolism.

Gender	Early Saturation	Saturation	Non-Saturation
Male	52 (54%)	15 (16%)	29 (30%)
Female	17 (19%)	34 (37%)	40 (44%)

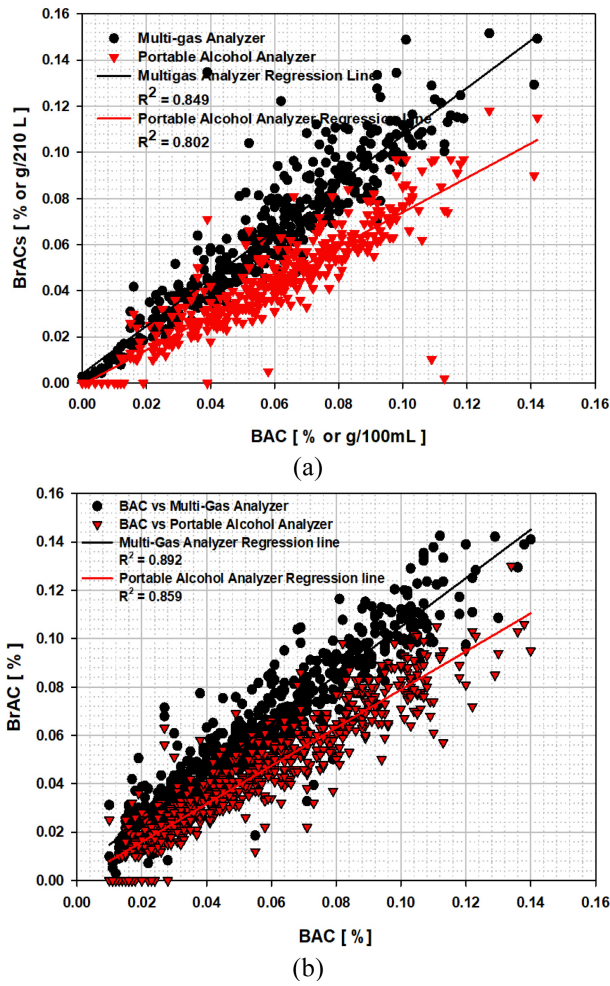


Fig. 2. Relationship between BACs and BrACs measured by two different analyzers: (a) male, (b) female.

The partition ratios as functions of BACs are shown in Fig. 3. In these figures, the partition ratio is divided into two regions—before and after 60 min of alcohol intake and their average values are listed in Table 2. The average value of T_{max} , which is the average time that BACs reach the highest value after consuming alcohol in this study, was 55 min [13]; therefore, the partition ratios were calculated with this time reference.

During the absorption time of alcohol (less than 60 min after consuming alcohol), the averages of the Q-factor were small compared to the value used in the screening of drunken drivers. The average partition ratio was slightly higher in females than in males. The standard deviation in each group showed a large distribution: approximately 300 in the male group and 300–600 in the female group. Therefore, the Q-factor and the standard deviation of the Q-factor were small in the Korean women. However, when entire data were calculated without time limitations, the average partition ratio of healthy

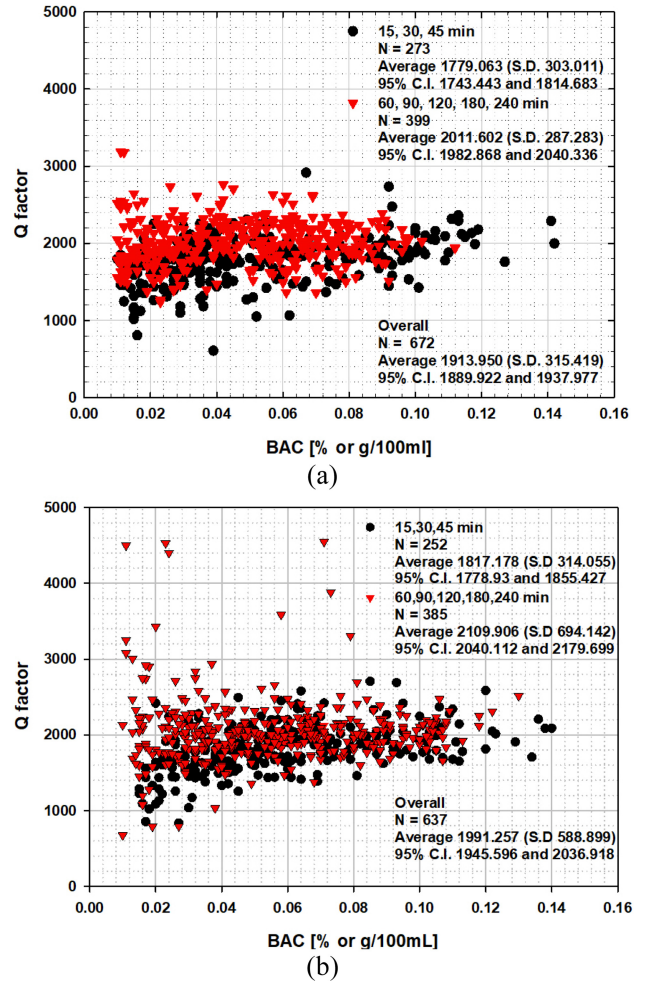


Fig. 3. Partition ratios (Q-factor) as a function of BACs: (a) male, (b) female.

Table 2. The average values of partition ratio (Q-factor).

Gender	< 60 mins	≥ 60 mins	Average values
Male	1779	2011	1913
Female	1817	2109	1991

Korean males and women were calculated as 1,913 and 1991, respectively.

The partition ratio ($Q=2,011$ or 2109 after 60 min) is an important factor in calculating the estimated BACs when the extrapolated BAC is needed to evaluate the initial BAC value by the police. In addition, the average partition ratio, after drinking alcohol without a time limit, would be essential to the manufacturers of BAIDs because the user of BAIDs would be required to pass the rolling retest while driving [14,15]. Therefore, it would be valuable to determine the relationship between BACs and BrACs as a parameter of the partition ratio; this relationship is presented in Fig. 4. As shown in Fig. 4 (a), when $Q=2,100$ was

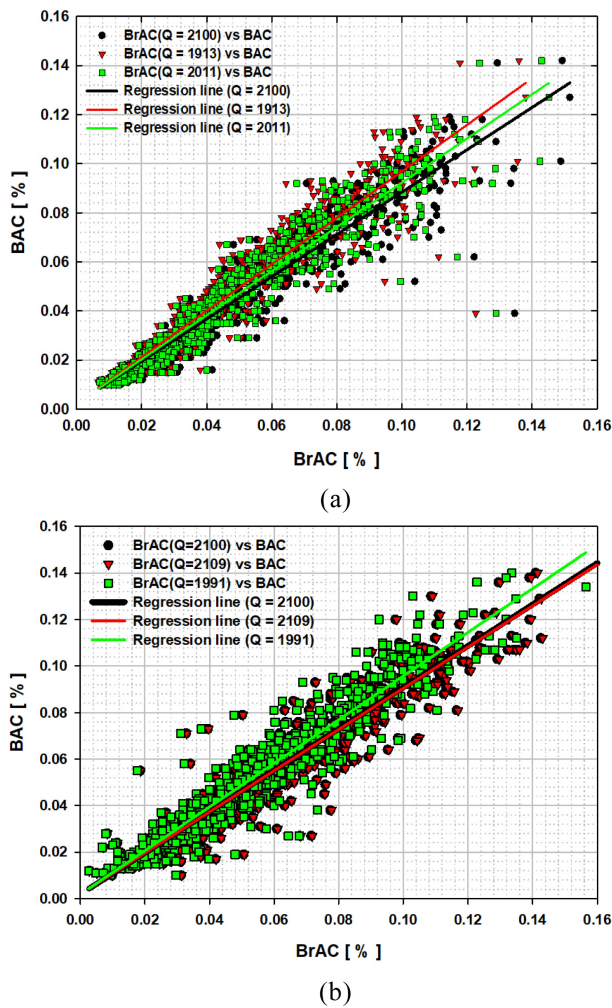


Fig. 4. BACs vs. BrACs according to the partition ratio, Q: (a) male, (b) female.

adopted to calculate the BACs, the actual BACs were overestimated by the exhaled breath samples. The regression line was $y = 0.8615x + 0.0023$ with $R^2 = 0.892$ ($Q = 2,100$). It is certain that the measurement results would not be favorable for healthy Korean males. However, when the partition ratio was less than 2,100, as noted by $Q = 1,913$, the BrAC product by Q-factor showed more favorable matches than the previous results with the regression line $y = 0.9457x + 0.0023$, with $R^2 = 0.891$. For Korean women, the Q-factor ($Q = 1,991$) suggested in Fig. 3(b) is more reasonable, as shown in Fig. 4(b).

To ensure the replacement of invasive BACs measurements, Bland–Altman plots [16] according to the partition ratios ($Q = 1,913$ for males and $Q = 1,991$ for women) are presented in Fig. 5. If there is no or a small bias in the Bland–Altman plot, it is well known that a new experimental apparatus or method could be replaceable in medical checkups. As described in a

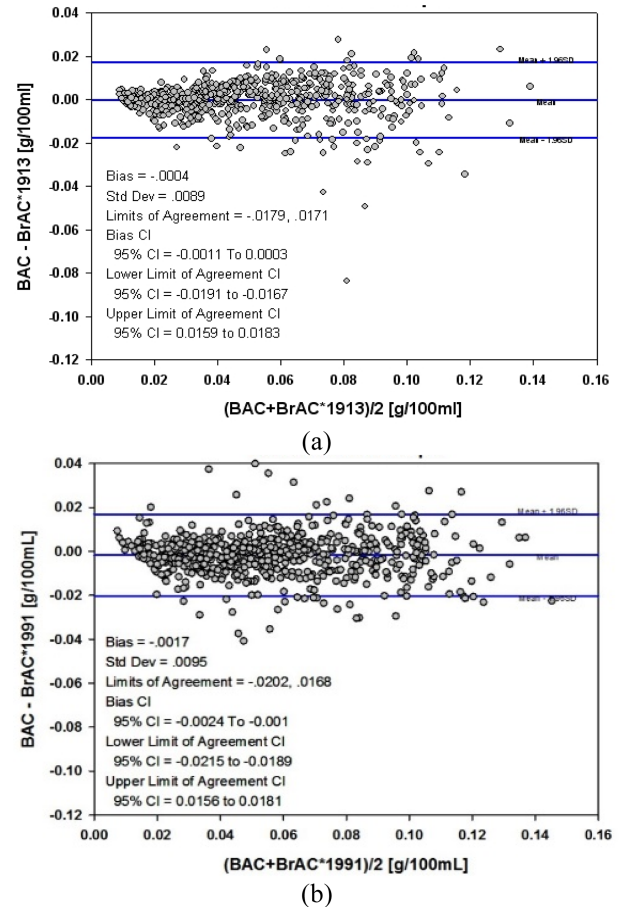


Fig. 5. Bland-Altman plots of healthy Korean; (a) male ($Q = 1,913$), (b) female ($Q = 1,991$).

previous report [12], when the partition ratio Q was 2100, there was a bias of -0.0052 and its 95% CI ranged from -0.0059 to -0.0045 . However, when the Q -factor of 1913 was multiplied by BrACs to calculate BACs, the bias was -0.0004 for males and -0.0017 for women. Because the limit of agreement was offset toward negative values in the case of $Q = 2,100$, the measured values from the multi-gas analyzer clearly exaggerated the BACs, as shown in Fig. 4. From the results shown in Fig. 4 and 5, it is clear that the average value of the partition ratio calculated with the whole interval BAC/BrAC ratio is more reasonable than the value of $Q (=2,100)$ used in the current breathalyzer for healthy Koreans.

Table 3 lists the ethanol concentration versus CO_2 concentration as a function of time interval intaking alcohol. Ethanol concentrations peaked in both cases; however, the concentrations of exhaled carbon dioxide show a relatively uniform distribution in this study. It can be inferred from Table 3 that the ethanol and carbon dioxide should be measured simultaneously to assure the screening procedures of drunken drivers.

Table 3. Ethanol vs. CO₂ concentrations as a function of time (one of early saturation types).

Time [mins]	Ethanol Conc.[ppm]		CO ₂ Conc. [ppm]	
	Male	Female	Male	Female
15	143	160	27,219	29,976
30	217	239	27,014	26,753
45	216	258	27,150	30,628
60	207	248	25,583	28,054
120	139	193	26,789	32,203
180	113	163	29,129	35,376
240	87	132	30,691	32,859

4. CONCLUSIONS

To reveal the relationship between BACs and BrACs in healthy Koreans, extensive medical tests were performed for the first time. Healthy Koreans showed three characteristic BAC patterns of alcohol metabolism; however, more than 50% of the participants showed saturation patterns with BACs peaks at less than 60 min. As the BACs are underestimated by using conventional value ($Q=2,100$), it would be better to consider new values ($Q=1,913$ for males and $Q=1,991$ for women) or execute more profound research to reveal the exact partition ratio for healthy Koreans. In addition, to prevent false drinkers, it is recommended that alcohol and carbon dioxide concentrations be analyzed simultaneously.

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