The RELATIONSHIP between BAC and BrAC of HEALTHY KOREAN MALE

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ABSTRACT

BrACs (Breath alcohol concentrations) are often converted to the corresponding BACs (blood alcohol concentrations) by multiplying a partition ratio, Q. However, according to the previous researches, it has been revealed that it depended upon the nations. So, the partition ratio (or Q-factor) of healthy Korean adult males and its correlation to some variables including TBW (total body water), BMI (body mass index), BFM (body fat mass), and PBF (percentage of body fat) were revealed. The average of partition ratio did show particular difference around 100 when the subjects were divided with two sets: below and above the average of TBW. The partition ratio of Korean healthy males showed 1,913 (95 % confidence interval (CI) from 1,889 to 1,937) for whole time intervals. However, when Q was averaged after peak BACs, it gave 2,011 (95 % CI range from 1,982 to 2,040). Bland-Altman plots revealed the compatibility of measurement method of multi-gas analyzer, and the biases according to the partition ratios (Q=2,100 and Q=1,913) gave -0.0052 (95 % CI from -0.0059 to -0.0045) and -0.0004 (95 % CI from –0.0011 to +0.0003), respectively. From this study, the partition ratio of Korean healthy males has been reported for the first time with massive medical experiments.

INTRODUCTION

The vehicles are getting more and more important in modern life for traveling, commuting, and logistics etc.. As the numbers of automobiles increase, however, road traffic safety become a national-wide matter in order to diminish road traffic accidents and also fatalities. In Sweden, they declared Vision Zero slogan in order to eliminate any victom from the road traffic accidents [1]. Among the road traffic accidents, alcohol-related crashes and fatalities are the major issues around the world in terms of improving more safe road traffic situation. In order to alleviate alcohol-related accidents, most of nations use alcohol sensing appartus for screening drunken drivers and it measures BrAC by using optical components or fuel-cell type devices [2, 3]. Currently, the breathalyzers for monitoring BrAC are widely used in the world in order to screen impaired drivers at the roadside. The regal limit for impairments are 0.08 % in U.S. and 0.05 % in most European countries. Although, Sweden adopted a 0.05 % BAC limit in 1950s, the regal limit of BAC has been recently lowered to 0.02 % in order to improve traffic safety further. By lowering regal limit, James and Robert reported that fatal crashes and severe personal injuries have been decreased and settled down more safe road traffic situation than ever [4]. In 1962, Korean government legitimated the road traffic law in order to enforce alcohol-impaired driving. After four decades, BrAC analysis for road traffic offences is regulated in 2006, setting a regal BAC limit of 0.05 % for driving. Also, there were several trials to decrease the regal limit of BAC to 0.03 % for road traffic safety and for decreasing alcohol-related fatalities.
Since the consumed alcohol is eliminated from the body also through the exhaled air that is coming from deep lungs [5, 6], the measurement of BrAC has been evaluated to analyze BAC for decades. The relationship between BAC and BrAC has been studied for long time, so BAC is currently converted from BrAC by multiplying by a BAC/BrAC ratio known as partition ratio or conversion factor, Q. The US NHTSA (National Highway Traffic Safety Administration) uses a conversion factor, Q, as 2,100 [7], this value 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 to 2,300 [8]. Furthermore, the recent study showed that the conversion factor could be ranged from 2,225 to 2,650; Jones and Andersson reported the average conversion factor was 2,448 in their article [9], Pavlic et al. presented the time dependency of Q ranged from 2,225 to 2,650 [10], and Lindberg et al. showed that the BAC/BrAC ratio was 2,251 in case of Swedish subjects [1].  

Since the conversion factor, Q, is related to BAC determined from breathalyzer and also it is relatively different from country to country, the aim of this study is to identify the BAC/BrAC ratio of Korean healthy males and its correlation to some variables: TBW, BMI, BFM, and PBF in this research.

MATERIALS AND METHODS

Subjects

One hundred and one individuals, whole healthy males, were enrolled in this study as paid volunteers. Ages ranged from 20 to 50 years and body weights ranged from 55 to 78 kg. Whole subjects were not heavy consumers of alcoholic beverages (less than two bottles of Soju (20 % (v/v) in their regular lifestyle). The study was approved by the Ethics committee of Konkuk University Hospital, Korea.

Experiment procedures

The volunteers were recruited by posting announcement through internet or public board. The volunteers were screened by psychiatric doctor with basic medical and psychiatric checkup containing physical examination, vital sign, CBC (complete blood count), LFT (liver function test), vital sign check, Alcohol Use Disorder Identification Test-Korea (AUDIT-K), CAGE (cut-down, annoyed, guilty, eye-opener) survey. Finally, 101 individuals were selected and participated in this research. Whole participants checked up their current physical status by measuring weight, height, TBW, BFM, PBF, and BMI, which were analyzed by InBody 720 (InBody Co., LTD.). Since it roughly took 2 minutes to analyze one breath sample, the volunteers were divided into ten groups. The volunteers 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 are allowed to rinse the mouth with drinking water in order to ensure the absence of mouth alcohol before the first testing, however, not allowed to drink water until 2 hours after consuming whole alcohol. The samples (one blood and two breath) were obtained at timed intervals of 15, 30, 45, 60, 90, 120, 180, 240 minutes after drinking alcohol in order to reveal the relationship between BAC and BrAC for healthy Korean males. The BAC/BrAC ratio was analyzed according to the four body index (TBW, BFM, PBF, and BMI). In order to avoid complexity in subsequent data interpretation, no food and mixing of different alcohol were allowed, furthermore, violent physical activity was not allowed during the experiment also.

Collection of blood and BAC analysis

After drinking of alcohol within 15 minutes, a blood sample of 2 mL was drawn from the proximal stopcock which is 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 EDTA (Ethylene-diamine tetra-acetic acid). The tubes were stored in a refrigerator at 4 to 6 °C and brought to Neodin medical Institute located in Seoul the day after the experiments were finished for each sub-group. Each delivered blood sample was analyzed by enzymatic methods (COBAS Integra 800, Roche USA) twice times in order to reveal BAC.

BrAC Measurements

One breath sample for each volunteer was collected with 3 liter non-odor bag (TK005-N-003, BMS Corp., Japan) at the same time the blood sample drawn from the indwelling catheter and analyzed with INNOVA-1312 multi-gas analyzer (LumaSense Technologies, Denmark). The analyzer used in this study consists of two main components:
optical and acoustical measurement units. By adopting photo-acoustic measuring principles, it could analyze gases from ppb to ppm level. So, this analyzer has been selected as a reference BrAC measurement apparatus in this study. However, in order to enhance the measurement reliability, the multi-gas analyzer was sent back to the manufacturer for adding a new filter (for ethanol measurement) and was calibrated in order to secure the accuracy of measurement. After measuring each breath sample three times with multi-gas analyzer, the average BAC has been converted ppm level to percentage level by multiplying conversion factors. The other breath samples for each person were measured by using four portable breathalyzers (AL9000, Sentech Corp., Korea) at timed intervals of 15, 30, 45, 60, 90, 120, 180, 240 minutes after drinking alcohol. Then four-measured values were averaged after finishing tests for comparison. Each portable breathalyzer was also calibrated before the experiments to alleviate the reliability issues raised in fuel-cell type breathalyzer.

**Calculation of Q**

The partition ratio, Q, was individually calculated for each subject from the ratio of the mean BAC value to the average BrAC value determined from the multi-gas analyzer in this study. However, the ratio of BAC to BrAC value, Q, assumed to be 2,100 in portable breathalyzer because Korean jurisdiction admitted this value currently. All statistical parameters such as average, standard deviations of average and 95 % confidence intervals for the calculated parameters were acquired with MS Excel 2013 and also Sigma Plot 12.5.

**RESULTS and DISCUSSION**

After arranging BAC results according to the elapsed times, Korean adult males show three characteristic alcohol metabolism patterns as shwon in Figure 1: left-shifted, standard, and right-shifted patterns (five mixed patterns are excluded in this analysis). The numbers of subjects belonged to each category denote as n in Figure 1. Compared to Figure 1 b), left-shifted pattern reveals no peak of alcohol concentration in their blood, however, right-shifted (also standard) type presents a peak alcohol concentration after 90 mins later in this subject. As can be inferred from Figure 1, the alcohol metabolism of Korean adult males could be divided into three characteristic patterns.

![Figure 1. Three characterisitic patterns of BAC: a) left-shifted (n=29), b) standard (n=52), c) right-shifited(n=15).](image)

**Figure 2. Relationship between BAC and BrAC with two different BrAC measurements.**

![Figure 2](image)
Figure 2 shows the relationship between BACs and BrACs measured by two different apparatus: multi-gas analyzer and portable breathalyzer with an assumed partition ratio, Q=2,100 (N=808, numbers of whole measured values). In case of multi-gas analyzer, BACs are overestimated as depicted in Figure 1 a); regression line \( y=0.8852x+0.0006 \) with \( R=0.962 \). However, when breath alcohol concentrations are measured with portable breathalyzer, BACs were underestimated as can be seen in Figure 1 b); regression line \( y=1.1628x+0.0062 \), with \( R=0.939 \). Even though there was small bias that is roughly 10 % of the error (± 0.005 %) with the measurement of multi-gas analyzer, the data measured by breathalyzer showed little higher offset value in BAC measurement. Furthermore, even BACs had some meaningful values, the breathalyzer didn’t monitor the actual BACs in some subjects.

Since there were some differences between BAC and BrAC measurements in both cases when the partition ratio, Q, was used as 2100, the partition ratio was calculated according to the elapsed time. Low BACs which are less than 0.01 % are excluded in this analysis in order to increase the accuracy of partition ratio. Also, the average value of \( T_{\text{max}} \), which means the average time that BAC reaches the highest value after consuming alcohol in this study, was 55 mins [11], so the partition ratios were calculated with this time reference and showed as in Figure 3. During the absorption period (which was less than 60 mins after consuming alcohol), average of Q was 1,779. However, after 60 mins (this time intervals belonged to the digestion of alcohol), the average partition ratio was 2,011. Furthermore, when whole data were calculated without the time limitation, the average partition ratio of healthy Korean males was calculated as 1,913.

When total body waters were above and below the average value (42.4 Liters), the average of Q-factor was 1,903 (95% C.I. 1,870 to 1,938) and 1,999 (95% C.I. 1,966 to 2,033), respectively. In terms of BMI, the average of BMI was 25 for healthy Korean male. When BMI was above the average value, the partition ratio showed 1,935 (95% C.I. 1,887 to 1,983). When the partition ratios were categorized into body fat mass (BFM) and percentage body fat (PBF), the averages of partition ratio presented 1,950 (95% C.I. 1,916 to 1,983) and 1,957 (95% C.I. 1,924 to 1,990) when BFM and PBF are above the average values, respectively. The data related to partition ratio according to body index were listed in Table 1.

### Table 1. Partition ratio according to body index (excluded BACs less than 30 mins)

<table>
<thead>
<tr>
<th>Categories</th>
<th>BMI Above Ave.</th>
<th>BMI Below Ave.</th>
<th>TBW Above Ave.</th>
<th>TBW Below Ave.</th>
<th>BFM Above Ave.</th>
<th>BFM Below Ave.</th>
<th>PBF Above Ave.</th>
<th>PBF Below Ave.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average values</td>
<td>1,935</td>
<td>1,951</td>
<td>1,903</td>
<td>1,999</td>
<td>1,950</td>
<td>1,941</td>
<td>1,957</td>
<td>1,934</td>
</tr>
<tr>
<td>95% C.I. Lower Limit</td>
<td>1,887</td>
<td>1,924</td>
<td>1,870</td>
<td>1,966</td>
<td>1,916</td>
<td>1,905</td>
<td>1,924</td>
<td>1,898</td>
</tr>
<tr>
<td>95% C.I. Upper Limit</td>
<td>1,983</td>
<td>1,979</td>
<td>1,938</td>
<td>2,033</td>
<td>1,983</td>
<td>1,976</td>
<td>1,990</td>
<td>1,979</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>315</td>
<td>284</td>
<td>308</td>
<td>267</td>
<td>285</td>
<td>282</td>
<td>284</td>
<td>305</td>
</tr>
</tbody>
</table>

The partition ratio (Q=2,011 after 60 mins later) would be an important factor in order to calculate the estimated BAC when the extrapolated BAC is needed to evaluate initial BAC value [12] by police. Also the average partition ratio, after drinking alcohol without time limit, would be essential to the manufacturer of BAIIDs (breath alcohol ignition interlock devices) since the user of BAIIDs would be requested to pass the rolling retest during driving [13, 14]. So, it would be valuable to know the relationship between BACs and BrACs as a parameter of partition ratio and showed their relationship in Figure 5. As can be seen in Figure 5, when
Q=2,100 was adopted to calculate the BACs, the actual BACs would be overestimated by the exhaled breath samples. The regression line showed $y = 0.8615x + 0.0023$ with $R=0.944$ in this case ($Q=2,100$). It would be certain that the measurement results can be not favorable to Korean healthy males. However, when the partition ratio is less than 2,100, as denoted in $Q=1,913$ (depicted in red dots), BrACs product by Q showed more favorable matches that the previous results with regression line, $y = 0.9457x + 0.0023$, with $R=0.944$.

In order to assure the capability of replacement of invasive BAC measurement, Bland-Altman plots according to the partition ratios ($Q=2,100$ and $Q=1,913$) have been presented in Figure 6. If there is no or small bias in Bland-Altman plot, it is well known that a new experimental apparatus or device could be replaceable in medical checkup etc. As described in Figure 6 a), when the partition ratio, Q, was used as 2,100, there was a bias with -0.0052 and showed its 95 % CI from -0.0059 to -0.0045. Also the limits of agreement ranged from -0.0242 to 0.0138. Even though it is not shown in this article, when $Q=2,011$ is adopted, the bias showed -0.0029 and its 95 % CI marked from -0.0036 to -0.0022. However, when $Q=1,913$ was multiplied to BrACs in order to calculate BACs, the bias showed -0.0004 and revealed its 95 % CI from -0.0011 to +0.0003. Furthermore, the limits of agreement of evaluation ranged from -0.0179 to +0.0171. Since the limit of agreement had offset toward negative value in case of $Q=2,100$, the measured values from multi-gas analyzer would clearly exaggerate BACs as mentioned in Figure 5. From the results mentioned above in Figure 5 and Figure 6, it is clear that the average value of partition ratio calculated with the whole time interval BAC/BrAC ratio will be more reasonable than the value of Q (=2,100) used in current breathalyzer for Korean adult males.

**CONCLUSIONS**

In order to reveal the relationship between BAC and BrAC of healthy Korean males, the huge medical experiments has been executed for the first time in Korean medical study. Korean healthy males showed three characteristic BAC patterns, however, more than 50 % subjects (52 out of 101 individuals) participated in this
study showed a standard pattern with BAC peak around 50 mins. Even though there was no big differences in partition ratio in terms of BMI, BFM, and PBF, however, there was a meaningful gap in partition ratio when TBW is divided into two categories: above and below the average value. Since the partition ratio differed from the conventional value (Q=2,100) in case of Korean healthy males, it would be better to consider a new value (Q=1,913) or execute more profound research activities in order to calculate BACs from BrACs for Korean healthy males. The more reasonable partition ratio included Korean females will be reported shortly in the near future.

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