Absorption and Peak Blood Alcohol Concentration After Drinking Beer, Wine, or Spirits

Mack C. Mitchell Jr., Erin L. Teigen, and Vijay A. Ramchandani

Background: Both the amount and the rate of absorption of ethanol (EtOH) from alcoholic beverages are key determinants of the peak blood alcohol concentration (BAC) and exposure of organs other than gut and liver. Previous studies suggest EtOH is absorbed more rapidly in the fasting than in the postprandial state. The concentration of EtOH and the type of beverage may determine gastric emptying/absorption of EtOH.

Methods: The pharmacokinetics of EtOH were measured in 15 healthy men after consumption of 0.5 g of EtOH/kg body weight. During this 3-session crossover study, subjects consumed in separate sessions, beer (5.1% v/v), white wine (12.5% v/v), or vodka/tonic (20% v/v) over 20 minutes following an overnight fast. BAC was measured by gas chromatography at multiple points after consumption.

Results: Peak BAC (C_{max}) was significantly higher ($p < 0.001$) after vodka/tonic (77.4 17.0 mg/dl) than after wine (61.7 10.8 mg/dl) or beer (50.3 9.8 mg/dl) and was significantly higher ($p < 0.001$) after wine than beer. The time to C_{max} occurred significantly earlier ($p < 0.01$) after vodka/tonic (36 10 minutes) compared to wine (54 14 minutes) or beer (62 23 minutes). Six subjects exceeded a C_{max} of 80 mg/dl after vodka/tonic, but none exceeded this limit after beer or wine. The area under the concentration–time curve (AUC) was significantly greater after drinking vodka/tonic ($p < 0.001$) than after wine or beer. Comparison of AUCs indicated the relative bioavailability of EtOH was lower after drinking beer.

Conclusions: Findings indicate that BAC is higher after drinking vodka/tonic than beer or wine after fasting. A binge pattern is significantly more likely to result in BAC above 80 mg/dl after drinking vodka/tonic than beer or wine. Men drinking on an empty stomach should know BAC will vary depending on beverage type and the rate and amount of EtOH.

Key Words: Alcohol Absorption, Pharmacokinetics, Beverage Type Differences, Blood Alcohol Concentrations, Gastric Emptying Rate.

BECAUSE THE RATE of absorption of ethanol (EtOH) is greater than its rate of elimination, both the amount of EtOH consumed and the rate of absorption of alcoholic beverages are key determinants of the peak blood alcohol concentration (BAC) (Holt, 1981; Ramchandani et al., 2001a; Wilkinson et al., 1977). The rate of elimination of EtOH is determined largely by the activity of hepatic alcohol dehydrogenases (ADH), the primary enzymes that metabolize EtOH. ADH are saturated at relatively low concentrations of EtOH leading to a rate of elimination that is sometimes described as zero-order kinetics at higher concentrations and pseudo-linear or first-order at concentrations below the saturation of ADH (Wilkinson et al., 1977). Absorption of EtOH continues over a prolonged period of time after ingesting alcoholic beverages, with BACs continuing to increase until the rate of elimination exceeds the rate of absorption. For these reasons, the rate of absorption is a primary determinant of the peak BAC. As most of the effects of EtOH are related to the BAC, variables that influence the rate of absorption are of interest. EtOH is absorbed more rapidly during the fasting than the fed state (DiPadova et al., 1987; Horowitz et al., 1989; Jones, 2000; Roine et al., 1993). Furthermore, solid meals delay gastric emptying more so than liquid meals, and the rate of absorption of EtOH consumed with a solid meal is likewise slower than when consumed with a liquid meal, probably as a function of the rate of gastric emptying (Horowitz et al., 1989). Other studies indicate that food increases the rate of elimination of EtOH (Ramchandani et al., 2001b).

During both the fasting and fed states, the rate of absorption of alcoholic beverages is influenced by the

From the Department of Internal Medicine (MCM), University of Texas Southwestern Medical Center, Dallas, Texas; ABMRF/The Foundation for Alcohol Research (ELT), Baltimore, Maryland; and Section on Human Psychopharmacology (VAR), Laboratory of Clinical and Translational Studies, National Institute on Alcohol Abuse and Alcoholism, Bethesda, Maryland.

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Reprint requests: Mack C. Mitchell, Jr., MD, Professor and Vice-Chairman of Internal Medicine, University of Texas Southwestern, 5323 Harry Hines Blvd., Dallas, TX 75390-9309; Tel.: 214-648-5036; Fax: 214-648-6358; E-mail: Mack.Mitchell@utsouthwestern.edu

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concentration of EtOH in the beverage (Mellanby, 1919; Roine et al., 1993; Wilkinson et al., 1977). Previous studies reported variable results depending on the concentration of alcohol in the beverage. Some studies reported that higher concentration of alcohol in a beverage delays the rate of gastric emptying particularly after a meal (Haggard et al., 1941; Roine et al., 1991; Sedman et al., 1976). Many of these studies utilized 95% EtOH diluted to different concentrations in orange juice or water, although some used beer, wine, and spirits (both diluted and neat) during or after a standard meal. Other studies have reported that during the fasting state, dilute alcoholic beverages such as beer are absorbed more slowly than beverages with a high EtOH concentration such as whiskey (Mellanby, 1919; Roine et al., 1993).

Alcoholic beverages are consumed in a variety of situations, including with meals and at social gatherings where food may or may not be consumed with the beverages. In bars and taverns, alcoholic beverages are often consumed in the absence of food or several hours after eating, at which time the stomach is empty or nearly so. These social settings more closely resemble the fasting condition than drinking with meals. The purpose of this study was to determine during the fasting state, the kinetics of alcohol absorption and elimination and peak BACs after drinking the same amount of EtOH in the form of beer (5.1% v/v), white table wine (12.5% v/v), and vodka (diluted to 20% v/v with tonic water).

MATERIALS AND METHODS

Subjects

Fifteen healthy, nonsmoking men between the ages of 25 to 65 were selected for participation after responding to an advertisement. Subjects were screened for underlying medical conditions through a standardized history and physical examination and routine chemistry and hematological tests. The Alcohol Use Disorders Identification Test (AUDIT-C) questionnaire was used to evaluate subjects for possible alcohol-use disorders. Lifetime abstainers from alcohol and subjects with a score > 4 on the AUDIT-C, evidence of hypertension (blood pressure > 150/90), liver disease (including positive testing for hepatitis B or C), kidney disease, HIV infection, or other chronic illnesses based on history or biochemical parameters or hematological parameters were excluded from participation. Subjects with a body mass index (BMI) > 30 or < 18.5 were excluded. Subjects who were on any medications except occasional over-the-counter medications were excluded. Surreptitious smoking was evaluated by screening subjects with urine cotinine. Any subject with urine cotinine > 200 ng/ml was excluded.

Urine drug screens were performed at time of screening and on admission to the clinical research unit. A total of 66 men were screened to identify the 15 who participated in the study. The vast majority failed screening due to high AUDIT-C scores. Three participants were of European descent, 9 were African American, and 3 were Hispanic. The mean age of subjects was 37.8 years (range 26 to 55). The mean weight was 82.66 kg (range 68.6 to 96.4), and mean BMI was 26.35 (range 21.9 to 29.9).

Study Protocol

Subjects were required to abstain from alcoholic beverages for 48 hours prior to the study and to abstain from taking any over-the-counter or prescription medications including vitamins, with the exception of acetaminophen (< 1000 mg/d) for 14 days before the study. Subjects were admitted to the clinical research unit the day before the studies and remained as inpatients throughout the 3 days of study. The night before each study session, they were fed a standardized meal that was similar in composition on each of the days. Each subject was assigned a number, and all data were analyzed without personal identification. Subjects were monitored for adverse events throughout the entire period of the study from admission to discharge from the clinical research unit.

Administration of Alcoholic Beverages

Alcoholic beverages (0.5 g EtOH/kg body weight) were consumed over a 20-minute period beginning at 8 AM following an overnight fast. The volume of the alcoholic beverage was divided, so that half of the beverage was consumed within the first 10 minutes and the remainder within the next 10 minutes. Beer (5.1% v/v), white table wine (Chardonnay, 12.5% v/v), or vodka mixed with regular tonic to achieve a final concentration of 20% v/v was administered in a randomized fashion, so that 5 subjects received beer on day 1, 5 received wine on day 1, and 5 received vodka/tonic on day 1. The order of administration of the other beverages was also randomized on days 2 and 3. After a 20-minute period of consumption of the alcoholic beverages, the subjects remained fasting for 4 hours at which time they were allowed to eat a light lunch. All subjects completed each of the 3 beverage studies.

Blood Sampling

Venous blood samples were drawn from an indwelling catheter at specified times after administration of alcoholic beverages: Baseline, 10, 20, 30, 40, 60, 90, 120, 150, 180, 210, 240, 360, 480 minutes.

Analysis of Blood Ethanol

Whole BACs were analyzed at Mayo Laboratories (Rochester, MN) using head-space gas chromatography.

Pharmacokinetics Analysis

Noncompartmental analysis of individual concentration–time profiles was used to estimate the following pharmacokinetic (PK) measures:

- Peak concentration (C_{max})
- Time to peak concentration (T_{max})
- Area under the concentration–time curve (AUC): The AUC is a measure of exposure that integrates concentration across time. AUC was calculated using trapezoidal rule up to the last measured time point and was not extrapolated (using the typical linear extrapolation) due to the nonlinear PKs of alcohol.
- Mean residence time (MRT): The average time that drug remains in the body after administration (a time-based measure of exposure) was calculated as AUMC/AUC, where AUMC is the area under the moment curve, calculated from the concentration–time moment curve (concentration × time vs. time) using the trapezoidal rule.
- Apparent clearance (CL_{app}) calculated as Dose/AUC.
- Volume of distribution (V_{ss}) = MRT × CL_{app}
- Relative bioavailability: The relative bioavailability of alcohol following wine relative to spirits ($F_{W/S} = \frac{AUC_W \ \ Dose_S}{AUC_S \ \ Dose_W}$) and the

relative bioavailability of alcohol following beer relative to spirits ($F_{B/S} = \frac{AUC_B \ \ Dose_S}{AUC_S \ \ Dose_B}$) were estimated as measures of relative exposure following the beverages.

Statistical Analysis

Individual PK measures for each subject were tabulated and compared across sessions using repeated-measures analysis of variance (SPSS version 20.0; IBM, Armonk, NY). The level of statistical significance was set to 0.05. In case of significant differences, post hoc comparisons between sessions were performed using paired *t*-tests.

RESULTS

Figure 1 shows the geometric mean (SD) BAC for all subjects versus time. As the profile indicates, the peak BAC was higher after consumption of vodka/tonic than wine or beer. The time required to reach the peak BAC was also earlier following vodka/tonic compared with wine or beer.

Analysis of PK parameters indicated statistically significant differences among beverage types for C_{max}, $T_{max,}$ and AUC (Table 1). Statistical analysis using post hoc *t*-tests showed significant differences between all beverage pairs compared, such that the spirits (vodka/tonic) session showed the highest peak concentration and AUC, followed by wine and then by beer. The time to peak concentration was significantly shorter for spirits compared to wine and beer, while time to peak concentration did not differ significantly between wine and beer. MRT was shortest for spirits followed by wine and then by beer. These results indicate that spirits resulted in higher exposure compared to wine and beer, while beer resulted in lower and delayed exposure compared to spirits and wine.

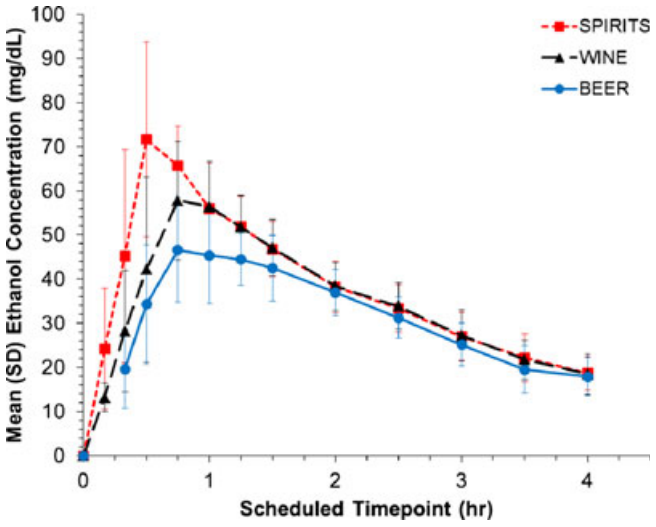

Fig. 1. Geometric mean values for blood alcohol concentrations following consumption of vodka/tonic (red squares), wine (black triangles), or beer (blue circles) are shown over time. Time zero represents initiation of consumption of beverages that was complete within 20 minutes.

The relative bioavailability for wine and beer relative to spirits was estimated from the AUC and adjusted for the absolute dose (in grams) administered. The estimated bioavailability for wine relative to spirits was 0.96 0.13 (SE) and was not significantly different from the theoretical value of 1 for bioequivalent formulations. The estimated bioavailability of beer relative to spirits was 0.90 0.02 (SE) and was significantly lower than the theoretical value of 1 for bioequivalent formulations. This finding implies that there is a 10% reduction in bioavailability of alcohol when administered as beer compared to spirits. Apparent clearance and volume of distribution showed higher values for beer compared to spirits or wine, probably resulting from the lower relative bioavailability of alcohol following wine and beer compared to spirits (Table 1).

In 14 of 15 subjects, the rate of absorption of spirits was greater than wine or beer. In 7 of the 15 subjects, the peak BAC exceeded 80 mg/dl (0.08%) after drinking vodka/tonic compared to beer or wine, and in 4 subjects, the peak BAC after vodka/tonic was more than 2-fold higher than after drinking beer. Peak BAC remained below 80 mg/dl in all subjects after consumption of this amount of beer or wine.

DISCUSSION

Our results show clearly that beer and wine are absorbed more slowly than vodka/tonic and that the peak BAC after drinking beer is significantly lower than the peak BAC after drinking a similar amount of EtOH as wine or vodka/tonic. The peak BAC after drinking wine was also significantly lower than after drinking vodka/tonic. In addition, the overall BAC exposure (AUC) following beer was lower than that for wine or vodka/tonic, which suggest a lower relative bioavailability for beer compared to the other beverages. While the estimated clearance for beer appears to be higher than that obtained for the other beverages, it is an "apparent" estimate because the route of administration is nonsystemic and artificially inflated as a result of the lower C_{max} and bioavailability for beer. Similarly, the apparent volume of distribution does appear to differ across beverages; however, this too may be confounded by the differences in bioavailability across the beverage types.

The beverages used in this study differ in both the concentration of EtOH and the caloric content of the beverages. The concentration of alcohol in beer was 5.1% v/v, wine was 12.5% v/v, and vodka was diluted to a concentration of 20% v/v in tonic. Thus, the concentration of EtOH in vodka/tonic (20%) was almost twice that of wine (12.5%) and 4 times the concentration of beer. Although this study was not designed to test the effect of concentration of alcoholic beverages directly, the findings suggest that, in the fasting state, less concentrated beverages such as beer and wine are absorbed more slowly than those that are more concentrated. Previous studies have not shown a consistent effect of concentration on the rate of absorption from different alcoholic beverages (Mellanby, 1919; Roine et al., 1993;

Table 1. Pharmacokinetic Parameters After Spirits, Wine, or Beer

PK Measure	Spirits	Wine	Beer	*p*-Value
C_{max} [mg%]	77.4 (17.0)	61.7 (10.8)	50.3 (9.8)	$F(2,28) = 30.757$, $p < 0.001$ *t*-tests: Spirits > Wine > Beer
T_{max} [hour]	0.6 (0.2)	0.9 (0.2)	1.0 (0.4)	$F(2,28) = 12.103$, $p < 0.001$ *t*-tests: Spirits > Wine = Beer
AUCt [mg*h/l]	1,510.9 (216)	1,379 (219.9)	1,193.6 (184.1)	$F(2,28) = 22.082$, $p < 0.001$ *t*-tests: Spirits > Wine > Beer
MRT [hour]	1.7 (0.2)	1.8 (0.3)	1.8 (0.2)	$F(2,28) = 3.968$, $p = 0.030$ *t*-tests: Spirits = Wine > Beer
CL_{app}	27.7 (3.6)	29.4 (5.3)	31.0 (4.2)	$F(2,28) = 6.527$, $p = 0.005$ *t*-tests: Spirits = Wine < Beer
VD_{app}	46.3 (7.5)	51.7 (8.3)	56.6 (8.9)	$F(2,28) = 14.291$, $p < 0.001$ *t*-tests: Spirits < Wine < Beer

Results of post hoc *t*-tests are shown to compare results among the 3 conditions (spirits, wine, or beer). Values shown are the mean with standard error in parentheses.

PK, pharmacokinetics measure; C_{max}, peak blood alcohol concentration; T_{max}, time to peak concentration; AUC, area under the concentration–time curve; MRT, mean residence time; CL_{app}, apparent clearance; VD_{app}, volume of distribution.

Wilkinson et al., 1977). Both the caloric content and other minor constituents of beer, wine, or vodka/tonic could potentially influence the rate of absorption. Although the calories from EtOH in each beverage were constant, beer has more total calories than either wine or vodka/tonic due to the carbohydrate content. An 80 kg subject would have ingested 409 calories as beer, 334 calories as wine, and 297 calories as vodka/tonic. The caloric content of beer could play a role in our findings because gastric emptying is influenced by the calories ingested more than the composition of the meal (Calbet and MacLean, 1997; Velchik et al., 1989). However, the differences in peak BAC between wine and vodka/tonic which have similar caloric value suggest that concentration is a more important determinant of the rate of gastric emptying and/or absorption of EtOH. Our findings do not permit a way to evaluate the effects of minor components of the beverages.

The findings in this study confirm previous observations that alcoholic beverages are absorbed rapidly during the fasting state, reaching a peak BAC within 1 hour (Jones, 2000; Roine et al., 1993; Wilkinson et al., 1977). We observed that the peak BAC occurred much sooner after consumption of vodka tonic (0.60 0.17 hours) than after drinking wine (0.91 0.23 hours) or beer (1.04 0.38 hours). This finding is internally consistent with differences in the rate of absorption of EtOH from beer, wine, or vodka/tonic.

EtOH is well absorbed by the intestinal mucosa (Gentry, 2000). As portal venous blood first passes through the liver before reaching the systemic circulation, the liver is exposed to most of the EtOH that is ingested. The liver is the primary site of metabolism of EtOH. Previous studies have shown that the bioavailability of EtOH is < 1 for very low doses of EtOH suggesting a possible "first-pass" effect (Gentry, 2000; Wilkinson et al., 1977). This effect is saturated at relatively low doses and thus would not apply to our findings. However, if alcoholic beverages are consumed and/or absorbed at a rate that is lower than the rate of metabolism and elimination by the liver, the amount of EtOH reaching target organs such as the brain would be negligible. The AUC reflects aggregate exposure of organs other than the liver to EtOH following ingestion of alcoholic beverages. The AUC after consumption of beer was significantly lower (geometric mean 160.9) than after consumption of wine (177.5) or vodka/tonic (196.8). This finding suggests that the exposure of organs such as the brain to EtOH may be lower after drinking equivalent amounts of EtOH in the form of beer compared to wine or vodka/tonic in the fasting state. Although a different amount of EtOH (0.3 g/kg body weight) was ingested, Roine and colleagues (1993) reported similar findings in AUC for beer, wine, and undiluted whiskey (40%) when consumed in the fasting state.

These findings have implications for individuals who consume alcoholic beverages in the absence of food. Drinking more concentrated beverages such as vodka/tonic is highly likely to produce higher peak BAC than when the same amount of EtOH is consumed as beer or wine. Although 12 ounces of beer, 5 ounces of wine, and 1.5 ounces of liquor (80 proof) contain approximately the same amount of EtOH, the peak BAC and the aggregate exposure to EtOH of organs other than the liver and gut may differ significantly depending on the type of alcoholic beverage and the rate at which it is consumed. Rapid consumption of alcoholic beverages, particularly those that are highly concentrated, in the absence of food, should be discouraged.

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