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Blood Alcohol Concentration Determined from Urine Samples as a Practical Equivalent or Alternative to Blood and Breath Alcohol Tests

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ABSTRACT: The value of urine tests for determining an equivalent blood alcohol concentration in driving under the influence (DUI) enforcement cases is reviewed from a historical, theoretical, and practical perspective. The limits of precision and accuracy that can be ascribed to urine alcohol results are demonstrated through an evaluation of actual case results wherein both a first void and a subsequent urine sample were analyzed and converted to an equivalent blood alcohol concentration (BAC) using a urine to blood conversion factor of 1.3 : 1.

KEYWORDS: criminalistics, alcohol, urine, driving (motor vehicle operation)

The analysis of urine as an indirect means of determining an equivalent blood alcohol concentration (BAC) in driving under the influence (DUI) investigations is a long established technique. Many states have incorporated urine testing into the "Implied Consent for Chemical Test" statutes, including California since 1966 (CA Vehicle Code, Sec. 13353).

Haggard et al [*1*] demonstrated, in a series of controlled experiments, that significant differences (> = 0.01% [3]) in determining an equivalent BAC from a urine sample could be precluded by using a sample collected within an hour after the subject has "voided" and applying a conversion factor of 1.3 : 1. Detractors of this hypothesis argue that complete "voiding" may not always occur because of voluntary or involuntary action by the subject. Therefore, they rationalize that an equivalent BAC determined from *any* urine sample could reflect a significantly different BAC than the actual BAC during the hour in which the urine sample was collected. Another argument used to discourage the use of urine for determining an equivalent BAC is that urine/blood correlation studies have shown the conversion ratio to range from 0.1 to 10 : 1 and therefore a mandated ratio is not applicable to individual cases [*2-7*].

These arguments are deceptive because the wide range of conversion ratios reported (0.1 to 10.0) results from using the relatively large (> 0.02%) *absolute* differences in alcohol concentration that occur well outside the range of practical legal importance (that is, 0.10% by California Law), or from first "void" urine samples; and then assumes that these extreme ratios should apply to urine samples taken 20 to 60 min after voiding where the true BAC is near the critical 0.10% level. The fallacy of these arguments is revealed through a critical review and analysis of

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[3]% as used in this paper represents a gram of alcohol per 100 mL of blood.

the physiology of urine alcohol production; published urine-blood (U/B) correlation studies; and 204 actual DUI cases from the author's laboratory wherein both the "void" and second urine "sample" results were analyzed and compared.

Physiology and Other Principles of Urine Alcohol Production

Lundquist [*8*] aptly said: "Knowledge of the laws governing the excretion of alcohol through the kidneys is important for the forensic evaluation of analytical findings when urine has been examined," a point that many critics of forensic urine alcohol testing seemed to have ignored.

The kidneys regulate hydration (water) and electrolytic balance by selective retention of useful solutes and the reabsorption of water. Urine is produced in the kidneys in a filtration process of the blood to eliminate waste products. Urine formation begins as a separation of blood cells and plasma. Water and filtrable solutes from blood plasma produce a fluid known as the glomerular filtrate (specific gravity [sp. gr.] 1.008 to 1.012). Approximately 20% of the plasma volume that passes through the kidney is converted producing 125 mL per minute of glomerular filtrate. The filtrate undergoes a reabsorption process for water and useful solutes. Urine passes from the kidney into the bladder via the ureter as the final product of this process. The average production rate of urine is between 0.55 and 1.25 mL per minute. The formed, concentrated, urine exhibits a higher and broader range of specific gravity than the glomerular filtrate: 1.015 to 1.025 [*9, 10*].

All experiments and observations directed at elucidating the laws that govern urine alcohol formation and their forensic science application, which have been reported in the literature, support the following general laws [*1, 8, 10, 11–16*]:

1. The urine alcohol concentration (UAC) is based upon the relative water concentration between whole blood (measuring media) and urine.
2. An increase in the diuretic state does not alter the relative concentration of ethanol in the water phase of blood or urine.
3. The human kidney cannot produce urine with a concentration of ethanol higher than that of the water phase of the blood perfusing through the kidneys where the urine is formed. The kidneys, therefore, *cannot* concentrate ethanol in urine.
4. The elimination of ethanol through urine is dependent upon the glomerular filtration rate and upon the quantity of alcohol in blood (and hence the BAC) which, in turn, affects the body's primary elimination rate at low level alcohols.
5. Conversion ratios used to obtain the equivalent BAC from urine sampling give the best agreement during the post-absorptive state of the alcohol curve.
6. Urine sampling constitutes a "pooled" sample collected over time during which the ethanol level is subject to change.
7. The second "sample" represents the average UAC from last "void" to the time of collection.
8. Whatever the ethanol concentration in a converted urine "sample" (that is, UAC/1.3 to 1.5 from cooperative subjects), one can confidently say that the blood then or earlier has at least reached the same concentration.

Frequency of Urination

A concern of many law enforcement officers is the time necessary for a second "sample" collection. For an apparent healthy subject, the frequency of urination depends upon the rate of production, diuresis, and fullness of bladder. The initial impulse to "void" occurs at a bladder volume of 150 mL while pronounced discomfort is indicated at 400 mL [*10*]. Under normal conditions, the urge to urinate may occur between 2 and 4.5 h. Miles [*13*] demonstrated that alcoholic consumption can increase urine production from 1 mL per minute to 7 to 12 mL per minute and that the diuretic effect follows the alcohol curve reaching its "crest about simultaneously with the alcohol urine curve. . . ." Alcoholic diuresis may produce an urge to urinate in 13 min and discomfort in 34 min. In our 204 cases (Tables 1-3 and Fig. 1), the increased diuretic effect from alcohol consumption was readily visible in that the average time for the second "sample" was 25 min.

Some pathological conditions affecting urine output have been described. The condition of increased urinary output, polyuria, is associated with diabetes and some types of central nervous system injuries. The condition of decreased urinary output, oliguria, has been described as an "ominous sign" when fluids have not been restricted. Oliguria is associated with the abnormal accumulation of fluids (edema) in the body, serous fluid in the abdominal cavity (ascites) and shock. Oliguria may be fatal if there is *no* urine output [*9*].

Since urine, like breath, is a nonintrusive sampling technique, subject cooperation is necessary. Southgate and Carter [*16*] described difficulties with subject cooperation as follows,

> Then a fact was brought to my notice, which I was soon able to verify—namely, that if there be one thing a drunken man will not do is to empty his bladder when requested. He will make every excuse and tell you any manner of fairy tales, but he will not micturate to order, even with a distended bladder. I think he becomes suspicious.

Since Carter's description of subject reluctance was published in 1926, the driving population has become more acquainted with the purpose of urine testing. Based on our years of experience of second "sample" collection the reported difficulty of some subjects to provide a second "sample" appears to be a function of subject cooperation rather than any physiological or pathological cause. One double urine case not included in the 204 reported cases was excluded because of the intentional dilution by "dipping" one urine vial. This conclusion was reached by the color difference, loss of chemical preservative and extreme difference in results (0.21 "void" and 0.00% "sample"). Continuous observation of the subject during sampling is therefore necessary to ensure sample integrity.

Forensic Science Sampling Considerations

The alcohol concentration of pooled urine collected in the bladder lags behind the BAC during the absorption phase, and with frequent voiding, eventually equilibrates higher than the blood alcohol concentration. The urine/blood ratio becomes relatively constant at 1.3 : 1 during the elimination phase [*1,4,8,10-12,17-19*]. Although there is frequent criticism regarding use of a correlation ratio before the elimination phase, *all* available information indicates that a ratio closer to "unity" or less than 1.0 applies and therefore the forensic science use of 1.3 will *underestimate* an equivalent BAC during absorption phase. During the elimination phase, the pooled urine may represent a falsely high alcohol concentration as the result of urine retention.

TABLE 1—*A statistical summary of all 204 DUI cases where subjects gave two urine samples.*

	% BAC Equivalent from the Analysis of Urine[a]		
	"Void" (V) (First Sample After Arrest)	"Sample" (S) (Second Sample 20 to 60 min After First Void)	Difference V−S
Average	0.206%	0.200%	−0.007
Range	0.007 to 0.355	0.018 to 0.349	. . .
Std. dev.	. . .	0.0547	0.0115
Variance	. . .	0.0030	0.0001

[a] % BAC equivalent is the actual urine alcohol concentration divided by 1.3.

TABLE 2—*All cases where "void" (V) minus "sample" (S) urine BAC difference is 0.015% or greater and* S − V *difference.*

	Case	Time from V to S, min	% BAC Equivalent "Void"	% BAC Equivalent "Sample"	Difference S−V
1	B-1954-1	25	.244	.214	−.030
2	B-2068-1	20	.182	.157	−.025
3	B-2100-1	44	.195	.171	−.024
4	B-2014-2	24	.170	.186	+.016
5	B-0220-2	21	.173	.128	−.045
6	B-0311-2	20	.178	.159	−.019
7	B-0334-2	30	.153	.135	−.018
8	B-0384-2	25	.205	.182	−.023
9	B-0416-2	33	.187	.170	+.017
10	B-0441-2	20	.161	.125	−.036
11	B-0562-2	20	.263	.247	−.016
12	B-0625-2	27	.153	.123	−.030
13	B-0663-2	21	.283	.260	−.020
14	B-0679-2	20	.264	.245	−.019
15	B-0893-2	20	.252	.233	−.019
16	B-0917-2	27	.243	.224	−.019
17	B-1213-2	62	.258	.242	−.016
18	B-1438-2	20	.253	.237	−.016
19	B-0072-3	25	.178	.113	−.065
20	B-0560-3	20	.198	.182	−.016
21	B-0848-3	20	.131	.086	−.045
22	B-0852-3	20	.277	.253	−.024
23	B-0942-3	25	.142	.122	−.020
24	B-1034-3	22	.225	.208	−.017
25	B-1268-3	35	.224	.182	−.042
26	B-1279-3	20	.300	.316	+.016
27	B-1300-3	49	.123	.198	+.025
28	B-1368-3	34	.145	.125	−.020
29	B-1563-3	33	.217	.200	−.017
30	B-1741-3	23	.161	.142	−.019
31	B-1808-3	19	.209	.188	−.019
32	B-1831-3	20	.264	.237	−.027
33	B-2005-3	30	.150	.127	−.023
34	B-0261-3	28	.272	.258	−.014
35	B-2435-3	20	.216	.201	−.015
36	B-2550-3	33	.167	.223	+.056
37	B-2563-3	25	.191	.168	−.023

The longer the retention, the more falsely high the result may become. The elimination rate of alcohol from blood can add to this potential discrepancy. The elimination rate will not however be a significant factor during collection periods of less than 1 h because of the averaging effect from "pooled" sampling and the relatively small differences in the elimination rate. Therefore, the shorter the time period between urine formation and sampling, the tighter the range of reported conversion ratios become to corresponding blood levels.

The calculation of a theoretical range for a U/B ratio has been addressed by Haggard et al [*1*], Jones [*18*], and Lundquist [*8*]. The concept is important because empirical findings outside of the calculated range *must* be the result of the alcohol absorption/elimination phase, sampling procedures, or subject cooperation. We conclude that the relative water concentrations between urine and blood cannot account for ratios greater than 1.22. The basis for this conclusion is as follows.

Relative urine water concentrations can be described through specific gravity measure-

TABLE 3—*All cases where either the "void"* (V) *or "sample"* (S) *urine alcohol concentration is 0.12% BAC or less and* S−V *differences.*

	Case	Time From V to S, min	Alcohol Concentration Void Sample and (Void/1.3)	Alcohol Concentration BA Sample and (Sample/1.3)	S−V (÷1.3)
1	B-2042-1	20	.009 (.007)	.023 (.018)	+.011
2	B-0011-2	30	.134 (.103)	.127 (.098)	−.005
3	B-0503-2	21	.142 (.109)	.139 (.107)	−.002
4	B-0671-2	20	.068 (.052)	.053 (.041)	−.011
5	B-0968-2	22	.111 (.085)	.099 (.076)	−.009
6	B-0766-3	23	.141 (.108)	.137 (.105)	−.003
7	B-0848-3	20	.170 (.131)	.112 (.086)	−.045
8	B-1609-3	20	.101 (.078)	.101 (.078)	.000
9	B-2163-3	33	.038 (.029)	.046 (.035)	+.006
10	B-2360-3	28	.095 (.073)	.113 (.087)	+.014
11	B-2163-3	33	.038 (.029)	.046 (.035)	+.006
12	B-2251-3	26	.138 (.106)	.129 (.099)	−.007
13	B-2360-3	28	.095 (.073)	.113 (.087)	+.014

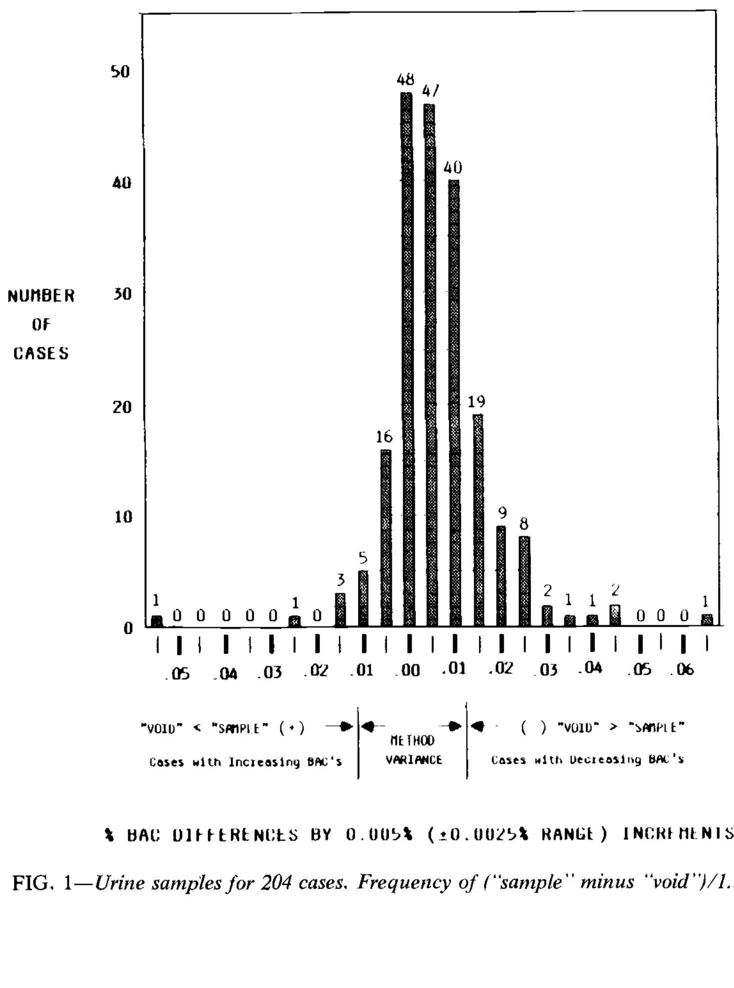

FIG. 1—*Urine samples for 204 cases. Frequency of ("sample" minus "void")/1.3.*

ments. Clinical urine dilution tests have demonstrated that normal specific gravity (1.010 to 1.025) drops to 1.003 after ingesting 1100 mL of water in 30 min [9]. A similar lowering of specific gravity may result from alcoholic diuresis. A low specific gravity (1.000 is equivalent to water) indicates a higher water concentration and therefore more alcohol in urine than would be present at a higher specific gravity.

The amount of water in blood varies depending upon the hematocrit. While a average hematocrit is often indicated to be 45% [20], men and women may average 47 and 42%, respectively [21]. Mason and Dubowski [22] report the range of normal hematocrit from 44 to 47% for the U.S. and European populations. They also suggest that most deviation in cellular volume involve lower percentages. Payne [6] reported five hematocrit readings in drinking subjects ranging from 42 to 45%. Hematocrit readings of 42 and 47% would give water concentrations in whole blood of 84.6 and 83.6%, respectively. These calculations are based upon the observation that variation in the hematocrit will not proportionly affect the plasma because plasma is already 93% water while blood cells contain only 73% water [20]. These calculations also recognize that the glomerular filtrate originates from plasma although the U/B ratio is calculated from whole blood. Blood and urine are therefore *not* independent and it seems reasonable that when blood may be higher than normal in water concentration, the urine would also be higher than normal. Using the known specific gravity of urine as an approximation of the water content, a theoretical ratio for urine to blood can be calculated as shown in Table 4.

Biasing water content beyond reasonable ranges, and in opposite directions, can mathematically produce a maximum, theoretical, conversion ratio. Assuming urine is 100% water at the same time blood is 82% (55% hematocrit) water will mathematically produce a ratio of 1.22 : 1.

Analysis of Published Urine-Blood Ratios

The reported studies (Table 5) are distinguished by first "void" and second "sample" studies and by the "type" of subject. All conditions of sampling except cooperation and physiological variation are assumed to be reasonably controlled either by monitors in the "volunteer" settings or police officers in the "arrested" field situation. Some of the ratios indicated below were calculated based upon published raw data. A "question mark" appears in columns where there is insufficient data to generate U/B ratios. "Samples" refers to actual paired sampling, some of which represent averaged data from more than one person (for example, Jones [23] obtained samples from 17 to 21 individuals but reported the average results). Averaged data was reported in "volunteer" cases only [1,13,23]. Where it was necessary to calculate the "mean U/B ratios," all paired samples including those in the absorption phase were included [1,13,23].

Several key conclusions can be gleaned from an analysis of the published data summarized

TABLE 4—*Using the known specific gravity of urine as an approximation of the water content, a theoretical ratio for urine to blood can be calculated.*

Urine, sp.gr.	Urine (water), %	Blood (water), %	Urine/Blood Ratio
	47% HEMATOCRIT		
1.025	97.5	83.6	1.16:1
1.010	99.0	83.6	1.18:1
1.003	99.7	83.6	1.19:1
	42% HEMATOCRIT		
1.025	97.5	84.6	1.15:1
1.010	99.0	84.6	1.17:1
1.003	99.7	84.6	1.17:1

TABLE 5—*Analysis of published data.*

Reference	Subjects	Total Samples	Mean U/B Ratio	Range U/B Ratios	% BAC Range	Cases with Ratios ≥1.5	Cases with Ratios ≥1.5 and at BACs ≥0.10%
			FIRST "VOID" STUDIES				
33	Alcoholic patients	372	1.23	1.0-2.3	.00-.48	?	?
34	arrested	66	1.17	0.81-1.67	.09-.32	2	2
26	arrested	76	1.26	0.69-1.71	.00-.34	3	2
8	arrested	69	1.44	1.14-1.64	.15-.20	?	?
	arrested	38	1.37	1.16-1.57	.20-.25	?	?
	arrested	46	1.33	1.07-1.55	>.25	?	?
24	arrested	7653	1.54	0.1-10	.00-.30	approx 3827	?
6	arrested	35	1.43	0.82-2.59	.04-.30	14	11
"Belfast data"	arrested	518	1.38	0.92-2.23	?-?	87	?
12	arrested	134	1.26	0.95-1.50	.08-.34	1	1
3	coroner	148	1.28	0.21-2.66	.02-.38	43	17
			SECOND "SAMPLE" STUDIES				
13	volunteer	8	1.28	0.85-1.56	.00-.04	3	0
16	volunteer	42	1.42	1.25-1.67	.04-.15	8	0
1	volunteer	22	1.3	½h 0.31->2.22	.00-.19	5	0
11	volunteer	91	1.24	0.63-1.50	.00-.19	1	0
8	volunteer	55	1.35	1.12-1.51	.05-.15	?	?
4	arrested	13	1.31	1.15-1.48	.12-.32	0	0
7	volunteer	69	1.09	0.30-2.22	.00-.20	4	0
15	volunteer	117	...	0.21-2.13	.01-.24	12	3
6	arrested	35	1.41	1.10-2.44	.04-.30	11	10
12	arrested	16	1.25	1.12-1.40	.15-.28	0	0
19	volunteer	...	...	1.3-1.4	>.03	0	0
	volunteer	...	...	>2.0	<.03	?	0
18	volunteer	7	1.57	0.75-2.36	.01-.08	3	0

in Table 5. A discussion of these results will show that "void" sampling and BAC comparisons produce a broader U/B ratio range than theoretically explicable based upon the known physiological limitation of relative water concentrations between urine and blood. The influences from the type of population studied will also be discussed, and the potential effect from uncooperative test subjects will be examined and shown to be the only reasonable explanation for the extreme U/B ratios reported by Payne et al [*6, 15*].

Void Versus Sample

Froentjes [*24*] depicts a normal distribution of U/B ratios for 7653 random "void" cases with a mean of 1.54 and states, "As can be seen at the tails of this curve, this ratio possesses extremely low values as well as extremely high values, from 0.1 to 10 or even lower or higher. These extreme values are physiologically explicable." The inference by Froentjes that U/B ratios higher than 3.0 are "physiologically explicable" is invalid because no U/B ratios greater than 3.0 were reported in *any* other literature reviewed for "void" or "sample" urines where the BAC was >0.10%. The extreme range of U/B ratios reported by Froentjes is undoubtedly the result of calculating U/B ratios at low BAC levels and from the exclusive use of "void" urine samples.

Haggard et al [*1*] demonstrated that even under normal conditions of frequent urination extremely high U/B ratios result at low BAC (that is, where the BAC is zero yet some alcohol remains in the urine). Haggard et al's data also show that urine retention for an hour or more can produce U/B ratios of 1.3 to 1.7 for blood alcohol levels greater than 0.10%; and, when the blood alcohol level falls below 0.10%, the ratio range increases from 1.7 up to 16.1. No ratios above 1.5 were reported at BACs of 0.10% or greater when urine sampling was conducted at 30-min intervals. Camps [*25*] and Haggard et al [*1*] have also described experiments where individuals have held their urine during sleep, and from the "morning" to "late afternoon." In these experiments, the calculated U/B ratios were infinitely high and 5.0, respectively.

Haggard et al's examination of "voids" collected after the urine had been held for 4, 5½, 6, and 7 h gave ratios from 1.25 to 25. Except for the 1.2 case, all cases were at BACs less than 0.10%. The U/B ratio of 25 was calculated from a BAC of 0.002% when the second urine "sample" was 0.051%. A salient point here is that second "samples" were collected 30 min later for another ratio determination and in each case the second "sample" BAC equivalent and the BAC were within ±0.005% including the highest BAC of 0.116%. This excellent correlation demonstrated by the second "samples" was found true from the onset of drinking to the final 0.002% BAC recorded 11 h after the first drink. Our Cases B-0072-3 and B-2550-3 further exemplify the potential error from relying on "void" urine samples where the difference between "void" and "sample" were, respectively, −0.06% and +0.05% over a collection period of 25 and 33 min.

By relying on Haggard et al's experiments with volunteer (cooperative) subjects showing no difference between the second "sample" and blood after long intervals of time, we can calculate the "void" ratio from our Case B-0072-3. This calculation assumes subject cooperation and defines the equivalent blood alcohol level as the "sample" divided by 1.3. Dividing the "void" alcohol level by the equivalent blood alcohol level ("sample"/1.3) produces a ratio of 2.04. This calculation performed on all first "void" samples of the 204 DUI cases reported below produced an average U/B ratio of 1.35 and a range of 0.51 to 2.04 (Fig. 1).

Ratios Calculated from Low Blood Alcohol Levels

Ellerbrook and VanGaasbek [*26*] summarized Miles' 1922 findings [*13*] as

> Miles, using very low blood alcohol concentrations, concluded that the urine-venous blood alcohol ratio is near unity in the first half hour after the ingestion of alcohol but that then "for an hour or more" it is 1.35 to 1.50. He obtained individual ratios of from less than 1 : 1 to more than 2 : 1.

The findings were described relative to *time* and not blood alcohol level. In 1981, Jones [*18*] described U/B ratios to vary over a wide range, "They are less than unity during the absorptive phase, between 1.36 and 1.49 for the first few hours of the post-absorptive period and thereafter in excess of a ratio of 2.0." Observations that relate the U/B ratio to *time* without regard to BAC level are erroneous as will be shown by the following.

In 1926, Southgate and Carter [*16*] extended Miles' findings ". . . with much larger doses of alcohol, and extending over a much longer period." In 1940 Haggard et al [*1*] measured urine and blood every half-hour for 11 h after consumption and found the 1.3 ratio to apply during the elimination phase down to 0.049% after which the ratio significantly increased. The findings of Miles [*13*] and of Jones [*18*] are *not* distinguishable from Haggard et al [*1*] or Southgate and Carter [*16*] in terms of blood alcohol levels. In 1961, Lundquist [*8*] described the rate of urine flow as a potential cause of "serious error, especially when the period is long and the blood ethanol concentration low. At high blood ethanol concentrations errors from this source will be insignificant." Analytical error is also described by Lundquist [*8*] as a cause of "appreciable spreading of the U/B ratio" (for example, the errors are in opposite directions and at ethanol levels less than 0.10%). In 1975, Zink and Reinhardt [*19*] stated

> With longer periods between micturation, for example up to one hour, the quotient alcohol in urine to alcohol in blood was low (0.5–1) in the initial stages after drinking; when the maximal

stage was past, a quotient of 1.3-1.4 was obtained. When the blood alcohol concentration fell to values less than 30 mg/100 mL the quotient could increase to more than 2.

Stevens et al [7] reported 69 cases involving "social" drinking. Only 27 of the 69 cases reported urine alcohol levels greater than 0.10%. Cases 36 and 37 gave U/B ratios of 0.39 and 2.22 when the urine alcohol levels were 0.020 and 0.024%, respectively. The range of ratios from all cases is 0.30 to 2.22. Considering the 27 cases where the urine alcohol is 0.10% or greater, the range narrows to 0.96 to 1.44. Considering all 19 cases in which the actual blood alcohol was 0.10% or higher, the range becomes 0.96 to 1.36. Clearly, as the blood alcohol level raises, the conversion ratio narrows.

Arrested Versus Volunteer Subjects

The potential errors in determining the U/B ratio from "voids" or low level alcohol cases are affected to a lesser or greater degree upon the sampling population. Alcoholic patient and coroner cases are representative of higher blood alcohols levels while volunteer subjects represent the lower alcohol ranges. Volunteer sampling will produce a broad ratio range as the result of low level alcohols. Arrested subject sampling that rely on "voids" will also produce a broader range than predicted by relative water concentrations. Alcohol levels from the driving population generally fall between patient/coroner cases and volunteers but are frequently determined based upon "void" sampling.

In addition to the amount of beverage consumed, the frequency of drinking is a critical variable that is often different between volunteer and arrested cases. Haggard et al [1] observed from the onset of drinking that no subjects were able to hold their urine for more than 6 h. Yet, after the maximal diuretic effect (from ½ to 2 h after drinking) had passed, some individuals were able to retain urine without discomfort for 7 h. Note that this experiment involved the rapid consumption of 250 mL of undiluted whisky which is not consistent with normal drinking of diluted alcohol over several hours. In the normal drinking situation, diuresis would occur also as the result of increased fluid intake as described by Miles [13].

Payne's Data

Payne's [6,15] data appear to stand alone for second "sample" studies. Lundquist [8] is the only other researcher that may have observed a subject with a ratio of 1.5 at alcohol levels greater than 0.10%. By raising the ratio ceiling from 1.5 to 1.6 for alcohol levels greater than 0.10%, Payne's data does stand alone. No cases were calculated from Fig. 13 of his 1966 article [15] that had ratios greater than 1.6 when the blood alcohol was 0.10% or greater; and, only 4 of the 35 cases reported in 1967 [6] exhibited ratios greater than 1.6. Of those four cases, only two (Nos. 10 and 25) exhibited ratios higher than 1.7. Case 25 is unique as the only second "sample" case with a ratio greater than 2.0.

Payne's "Belfast Data" lists ratios for 518 cases where U/B ratios were calculated from the first urine "void." Case 25 exhibits a higher ratio than *all* 518 first "voids." Payne's second "sample" for Case 25 was 0.310% while the blood level was reported as 0.127%. Since the urine is a pooled, averaged sample, and the kidneys cannot concentrate alcohol, the blood alcohol was at least 0.23% at some prior time. To hold urine for 7 h without discomfort as described by Haggard et al [1], case 25 must have already passed the high diuretic phase and had been in the elimination phase before the "void" collection period. The "void" sample collected 25 min prior was 0.316% showing a decrease in level through time. The reported ratio (2.44:1) is two times larger than the maximum theoretical ratio (1.22:1) based upon physiological variation. Any suggestion that this case represents only the urine collected during the 25-min period between "void" and "sample" and therefore represents a reliable U/B ratio is scientifically absurd.

Subject Cooperation

Second "sample" U/B ratios in excess of 1.5 and at BAC levels greater than 0.10% can be obtained as the result of incomplete "voids" by "uncooperative" subjects. An incomplete "void" is distinguishable from the residual urine *always* remaining after urination that accounts for the normally observable U/B ratio range of 1.1 to 1.5. Rentoul et al [27] have described experiments demonstrating the possibility of error from holding urine by sampling small amounts over time. They conclude,

> In practice, however, it does not appear to us to be of importance. Two factors are operative here: first, the discrepancy is not sufficient to be discriminatory against the motorist except under the most exceptional conditions; second, people just do not retain their urine for periods of four to five hours after the consumption of alcohol.

This point is substantially validated by our DUI case study.

DUI Case Study of the BAC

The practical equivalency of urine samples as advocated and demonstrated by Heise [17] is further validated by the following statistical analysis of 204 DUI cases (Tables 1-3 and Fig. 1) where both the "void" and "sample" urines were obtained and analyzed by the California Department of Justice Laboratory in Modesto. Our chemical analysis is done in duplicate by a modified Smith Widmark batch process. The mean result of duplicate analyses is reported. Although only the second urine "sample" is mandated for collection, all reported cases during this two-year study involved double urine samples. Variations of these duplicate analyses averaged 0.0026% with a standard deviation of ±0.0013%. Three sigma includes 88% of the data which is exactly what Chebyshev's theorem (distribution for any set of data) predicts. Four sigma (±0.0052%) includes 92% of the data. The chance of any two analyses falling outside of method variation and in opposite directions ("sample"-"void" calculations) is approximately 8% squared. Therefore, the reported "void" and "sample" collected over time from the same individual should not vary more than 0.010% from each other as the result of method variance. Differences greater than 0.010% of the reported values is then the result of the dynamic state of ethanol in all living individuals. Figure 1 shows the frequency distribution of the differences for the "sample" minus the "void" sample results for all 204 cases by 0.005% BAC increments. The distribution is skewed towards *negative* differences (that is, "sample" less than the "void" value). This frequency distribution shows that 199 of the 204 cases have reached a BAC plateau or are in the elimination phase of the BAC curve. In only 5 of the 204 cases was the "void" greater than the second "sample" value by more than the +0.012% difference that could be ascribed to combined method variance and this indicates that these cases were in the absorption phase of the BAC curve.

Although these cases do not represent a direct urine to blood correlation study, the inferences that can be drawn from this statistical analysis of "void" and "sample" urine results collected in actual DUI cases strongly support the practical utility and accuracy of urine sampling as an indirect means of determining a BAC. The inferences from this study that support the practical equivalency of urine for determining a BAC are:

1. In most cases, there is no difference between the "void" and "second" sample urines taken from the same person. The average difference between the converted (using 1.3) "void" and "sample" reflects a loss of 0.007% alcohol for an average collection time of 25 min. This difference corresponds to an average hourly elimination rate of 0.016% per hour.

2. Most individuals (199 of 204 cases) in the forensic science application have reached their BAC plateau or are in the elimination phase of the alcohol curve (Fig. 1). Only 5 of 204 cases were indicated to be in the absorption phase during the "void." Except for two cases, the greatest difference between the "void" and second "sample" during absorption was less than

0.02%. This contradicts the frequent claim of rapid consumption of numerous drinks immediately before driving.

3. In only 13 cases did either the converted "void" or "sample" BAC fall below 0.12% (Table 3). Of these 13 cases, only Case B-0848-3 (also noted in Table 2) showed a significant difference between the "void" and "sample" % BAC indicating an unusually long period of urine retention before the "void" was collected.

4. In this study, the average % BAC determined from the "void" and "sample" urines are 0.206 and 0.200%, respectively. These average values are, for all practical purposes, identical (within ±0.01%) to the same (Stanislaus County) DUI subject population demonstrating the statistical accuracy of the 1.3:1 ratio. Our urine sample study represents the composite result of numerous police agencies. A contemporaneous, average BAC of all represented agencies was not determined. However, in a two-year statistical comparison of the mean blood versus urine results from the Modesto office of the California Highway Patrol and the Modesto Police Department, a finding of "no significant statistical difference" between blood and converted urine was found using a student's t test and Z score critical value. These agencies represent the most frequent users of the laboratory's alcohol analysis section. That data (1981 blood cases), collected from 1974 through 1976, gave a combined mean value of 0.195% (Table 6).

Urine testing is analogous to breath testing. Both are nonintrusive techniques that determine a BAC from conversion ratios and require subject cooperation. Blood breath correlation studies conducted with evidential breath testers calibrated on the established 2100:1 (34°C) partition ratio have demonstrated that the distribution of the *measured* breath alcohol concentrations (BrAC) found is skewed towards a low estimation of the *actual* BAC and that in only very rare cases does the BrAC overestimate the actual BAC by as much as 0.02% [*28,23,18*]. The use of a higher partition ratio, such as 2300:1 would undoubtedly result in a more normal distribution of the *measured* BAC values around the *actual* BAC values; but this would also result in a significant number of cases where the measured BAC overestimates the actual BAC by more than 0.02% which would not be forensically acceptable. The use of a negative bias in breath alcohol tests has had a longstanding approval by the National Safety Council (NSC) Committee on Alcohol and Drugs [5]. The Committee recognized the requirements of the Ad-

TABLE 6—*Average % BAC determined from blood/urine tests compared to breath test in California DUI cases.*

Data Source: (No. Cases, Dates) (Type of Breath Test)	Average % BAC	
	Blood/Urine Test, %	Breath Test, %
1. CA/DOJ—Fresno 1000 blood/urine 1800 breath, 1980 Intoxilyzer, Model 4011 AW	0.190[a]	0.165
2. CA/DOJ—Modesto 2141 blood/urine 2121 breath 1974 to 1976 Intoxilyzer, Model 4011	0.195[a] (excludes all cases < 0.05 BAC)	0.170
3. Santa Clara County Laboratory of Criminalistics 1993 blood/urine 2094 breath, 1982 Intoxilyzer, Model 4011 A	0.201[a] (excludes all cases < 0.05 BAC)	0.170

[a]Urine tests comprise less than 5% of the total blood/urine cases. The average % BAC for blood/urine samples is about 0.01% lower when cases less than 0.05% are included.

ministration of Justice for conservative evidence and concluded that the continued use of the 2100 factor for the conversion of BrAC to BAC is warranted for law enforcement purposes [5].

Applying the same rationale to urine alcohol tests, a U/B conversion ratio of 1.5:1 could be applied rather than the established average of 1.3:1 to avoid any reasonable possibility of overestimating an equivalent BAC determined from a urine sample. If a 1.5:1 ratio were used to convert our 204 second urine "samples," the average BAC would be 0.173%, which is practically identical to the average BAC equivalent determined from breath using a similar subject population (Table 6).

Conclusions

Urine is a reliable and accurate alternative to sampling blood for alcohol determination when second "samples" collected within 1 h from voiding are provided by cooperative subjects and converted using a ratio of 1.3:1.

Urine/blood ratios greater than 1.22:1 are not the result of physiological variation.

The broad range for U/B ratios reported in the literature and reviewed in this paper using "void" urine samples (that is, 0.51 to 2.04) are the result of the ethanol absorption-elimination phase, sampling procedures ("void" versus "sample"), low level BAC, or subject cooperation.

When the BAC is 0.10% or greater and second urine "samples" are examined from cooperative subjects, there is no reasonable scientific basis to apply a urine/blood ratio greater than 1.5 to any individual case. As applied in forensic science cases with cooperative subjects, *if the second "sample" is used to determine the BAC using a ratio of 1.5:1 giving a BAC of 0.10% or greater, there is no scientific basis to believe that the actual sampling of blood would have produced a result less than 0.10%.*

As shown by our urine case study, the subject is almost always in the BAC plateau or elimination phase of the alcohol curve for the second "sample" urine. The average difference between the "void" and "sample" corresponds to the normal elimination rate. Only 2 cases in 204 was there an indication that there was active absorption occurring that resulted in a "sample" minus "void" difference greater than 0.02%.

The converted urine "sample" mean and BAC mean from separate individuals within the same population will, for all practical purposes, be the same (±0.01%) statistically demonstrating the accuracy of the U/B ratio used. The ratio of 1.3:1 produced a mean of 0.200% in 204 cases, while blood from 1981 cases gave a mean value of 0.195%.

Additional studies correlating second "sample" urine to blood from cooperative subjects below 0.10% may be warranted. The literature reviewed for this paper indicates that at some BAC below 0.10% the observed ratio from cooperative subjects increases from 1.3 to 2.0 or greater. For jurisdictions relying on per se legislation for BACs less than 0.10%, it is important to define more closely where a significant change occurs.

It appears from this analysis of published data and our DUI urine case studies that the opinions of those who advocate discouraging [5] or the complete abandoment [2] of urine alcohol tests, stems from an incomplete analysis or the erroneous application of currently available information or both.

The scientific validity of properly administered urine alcohol tests to determine an equivalent BAC, as revealed by this analysis and review, should be considered in addition to the following advantages of urine alcohol tests in structuring an efficient and effective chemical test program.

1. As a nonintrusive sample, urine is available without compulsion or recourse to medical personnel.
2. Urine samples can be preserved for a reasonable time period without appreciable loss of alcohol [29-32].
3. Urine can be analyzed for the presence of other drugs or intoxicating substances or both.

Recommendations

1. A second urine "sample" taken at least 20 min to 1 h after first voiding the bladder should be used to determine an equivalent % BAC.

2. To validate further the accuracy of a BAC determined from the urine sample taken after first voiding the bladder, and to determine if the BAC has increased or decreased during the time between voiding and the second urine "sample," at least a 30-mL portion of the "void" urine sample should be collected, analyzed, and reported together with the second urine "sample" results.

3. A U/B conversion ratio of 1.3 : 1 should be routinely applied to all urine samples in determining an equivalent BAC: however, for purpose of legal argument, it should be conceded that a reasonable potential variation up to 1.5:1 could apply in some cases.

References

[1] Haggard, H. W., Greenberg, L. A., Carroll, R. P., and Miller, D. P., "The Use of Urine in the Chemical Test for Intoxication," *Journal of the American Medical Association*, Vol. 115, No. 20, 16 Nov. 1940, pp. 1680-1683.

[2] Dubowski, K. M., "Driving While Impaired: A Proposal for Statute Change," *American Association for Clinical Chemists News*, Jan. 1983.

[3] Kaye, S. and Cardona, E., "Errors of Converting a Urine Alcohol Value into a Blood Alcohol Level," *American Journal of Clinical Pathology*, Vol. 52, No. 5, Nov. 1969, pp. 577-579.

[4] Morgan, W. H. D., "Concentration of Alcohol in Samples of Blood and Urine Taken at the Same Time," *Journal of the Forensic Science Society*, Vol. 5, No. 1, Jan. 1965, pp. 15-21.

[5] National Safety Council, "Recommendations of the Committee on Alcohol and Drugs, 1936-1977, Appendix F, Special Report on the Blood/Breath Conversion Factor," pp. 81-84.

[6] Payne, J. P., Foster, D. V., Hill, D. W., and Wood, D. G. L., "Observations on Interpretation of Blood-Alcohol Levels Derived from Analysis of Urine," *British Medical Journal*, Vol. 3, No. 3, Sept. 1967, pp. 819-823.

[7] Stevens, P. J., Mason, J. K., and Bowden, L. H., "Comparative Ethanol Concentrations in Blood and Urine During Social Drinking," *Medicine Science and the Law*, Vol. 6, No. 2, April 1966, pp. 96-102.

[8] Lundquist, F., "The Urinary Excretion of Ethanol by Man," *Acta Pharmocologica et Toxicologica*, Vol. 18, 1961, pp. 231-238.

[9] Faulkner, W. R. and King, J. W., "Renal Function," Chap. 17 in *Fundamentals of Clinical Chemistry*, N. W. Tietz, Ed., W. B. Saunders Co., Philadelphia, 1976, pp. 975-1014.

[10] Schwar, T. G., "Urine Alcohol," Chap. 24 in *Alcohol, Drugs and Road Traffic*, W. F. Cooper, T. G. Schwar, and L. S. Smith, Eds., Juta and Co., Capetown, 1979, pp. 259-266.

[11] Coldwell, B. B. and Smith, H. W., "Alcohol Levels in Body Fluids after Ingestion of Distilled Spirits," *Canadian Journal of Biochemistry and Physiology*, Vol. 37, No. 1, Jan. 1959, pp. 43-52.

[12] Dunnett, N. and Kimber, K. J., "Urine-Blood Alcohol Ratio," *Journal of the Forensic Science Society*, Vol. 8, No. 1, Jan. 1968, pp. 15-24.

[13] Miles, W. R., "The Comparative Concentrations of Alcohol in Human Blood and Urine at Intervals after Ingestion," *Journal of Pharmocology and Experimental Therapeutics*, Vol. 20, No. 4, Nov. 1922, pp. 265-319.

[14] Pawan, G. L. S. and Grice, K., "The Distribution of Alcohol in Urine and Sweat After Drinking," *The Lancet*, Vol. 2, No. 7576, 9 Nov. 1968, p. 1016.

[15] Payne, J. P., Hill, D. W., and King, N. W., "Observations on the Distribution of Alcohol in Blood, Breath, and Urine," *British Medical Journal*, Vol. 1, No. 5481, 22 Jan. 1966, pp. 196-202.

[16] Southgate, H. W. and Carter, G., "Excretion of Alcohol in the Urine as a Guide to Alcoholic Intoxication," *British Medical Journal*, Vol. 1, No. 3402, March 1926, pp. 462-469.

[17] Heise, H. A., "Concentrations of Alcohol in Samples of Blood and Urine Taken at the Same Time," *Journal of Forensic Sciences*, Vol. 12, No. 4, Oct. 1967, pp. 454-462.

[18] Jones, A. W., "Quantitative Relationships Among Ethanol Concentrations in Blood, Breath, Saliva and Urine During Ethanol Methabolism in Man," in *Alcohol, Drugs and Traffic Safety*, Vol. II, L. Goldberg, Ed., Almqvist and Wiksell International, Stockholm, Sweden, 1981, pp. 550-566.

[19] Zink, P. and Reinhardt, G., "Alcohol Concentration in Urine and Its Forensic Evidence," in *Alcohol, Drugs and Traffic Safety*, S. Israelstam and S. Lambert, Eds., Addiction Research Foundation, Toronto, 1975, pp. 579-581.

[20] Caraway, W. T., "Carbohydrates," Chap. 6 in *Fundamentals of Clinical Chemistry*, N. W. Tietz, Ed., W. B. Saunders, Co., Philadelphia, 1976, p. 243.

[21] Davidsohn, I. and Nelson, D. A., "The Blood," Chap. 4 in *Clinical Diagnosis by Laboratory Methods*, 15th ed., W. B. Saunders Co., Philadelphia, 1974, p. 110.
[22] Mason, M. F. and Dubowski, K. M., "Breath-Alcohol Analysis: Uses, Methods, and Some Forensic Problems—Review and Opinion," *Journal of Forensic Sciences*, Vol. 21, No. 1, Jan. 1976, pp. 9-41.
[23] Jones, A. W., "Precision, Accuracy and Relevance of Breath Alcohol Measurements," *Modern Problems of Pharmacopsychiatry*, Vol. 11, 1976, pp. 68-78.
[24] Froentjes, W., "An Analysis of 10,000 Blood Tests in the Netherlands," in *Alcohol and Road Traffic*, J. D. J. Harvard, Ed., British Medical Association, London, 1963, pp. 179-188.
[25] Camps, F., "Chemical Tests for Alcohol Intoxication," *Practitioner*, Vol. 195, No. 1167, Sept. 1965, pp. 342-345.
[26] Ellerbrook, L. D. and VanGassbeek, C. B., "The Reliability of Chemical Tests for Alcohol Intoxication," *Journal of the American Medical Association*, Vol. 122, No. 15, 7 Aug. 1943, pp. 966-1002.
[27] Rentoul, E., Smith, H., and Beavers, R., "Some Observations on the Effects of the Consumption of Alcohol and Its Relation to Road Traffic," *Journal of the Forensic Science Society*, Vol. 3, No. 1, Sept. 1962, pp. 2-10.
[28] Dubowski, K. M., "The Blood/Breath Ratio of Ethanol," *Clinical Chemistry*, Vol. 25, No. 6, June 1974, p. 1144.
[29] Bradford, L. W., "Preservation of Blood Samples Containing Alcohol," *Journal of Forensic Sciences*, Vol. 11, No. 2, April 1966, pp. 214-216.
[30] Glendening, B. L. and Waugh, T. C., "The Stability of Ordinary Blood Alcohol Samples Held Various Periods of Time Under Different Conditions," *Journal of Forensic Sciences*, Vol. 10, No. 2, April 1965, pp. 192-200.
[31] Hayden, P. M. A., Layden, M. T., and Hickey, M. D., "The Stability of Alcohol Content in Samples of Blood and Urine," *Irish Journal of Medical Science*, Vol. 1, No. 2, Feb. 1977, pp. 285-290.
[32] Smalldon, K. W. and Brown, G. A., "The Stability of Ethanol in Stored Blood, Part II, the Mechanism of Ethanol Oxidation," *Analytica Chemica Acta*, Vol. 66, No. 2, Sept. 1973, pp. 285-290.
[33] Jetter, W. W., "Studies in Alcohol, Part I, The Diagnosis of Acute Alcoholic Intoxication by a Correlation of Clinical and Chemical Findings; Part II, Experimental Feedings of Alcohol to Non-Alcoholic Individuals," *American Journal of Medical Science*, Vol. 196, No. 4, Oct. 1938, pp. 475-493.
[34] Bavis, D. F., "145 Drunken Drivers—A Blood and Alcohol Study," *Journal of Laboratory and Clinical Medicine*, Vol. 25, No. 8, May 1940, pp. 823-827.

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