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The Specific Gravity Adjustment in Urinalysis

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Over twenty years' experience with the specific gravity adjustment in urinalysis has been reviewed. It is concluded that this method of expressing results of analysis of urine for heavy metals, solvent metabolites, and radioactive isotopes is preferable to the unadjusted concentration. Complicating factors, which may affect the validity of specific gravity-adjusted values, include variations in diet and degree of sweating. The adjustment fails when applied to samples containing sugar.

As between measurement of rate of excretion per 24 hours and the specific gravity adjustment, the latter is generally preferable for practical reasons. In extreme cases values obtained by the two methods vary by a factor of five or more. In such situations the best method of expressing findings is uncertain.

IN 1945 a paper entitled "Evaluation of Urinary Lead Determinations: I. The Significance of the Specific Gravity" appeared in the *Journal of Industrial Hygiene and Toxicology*. The authors were Leo Levine and John P. Fahy,[1] both chemists from this laboratory. In the paper the so-called specific gravity adjustment was proposed for recording the results of urinalysis for lead. Instead of reporting the findings as milligrams per liter, the following formula, in which the specific gravity of the urine sample is incorporated, was suggested:

$$\text{mg/liter (adjusted)} = \text{mg/liter (actual)} \times \frac{1.024 - 1.000}{\text{sp gr} - 1.000}.$$

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Table 1.—*Effect of Specific Gravity Reference Temperature*

Temp of Sample, C	Reference Temp, C	Sp G	Concentration of Contaminant	
			Actual	Adjusted
25	25	1.006	0.05	0.20
25	4	1.003	0.05	0.40

The value 1.024 represented the mean specific gravity of the nearly 1,200 samples of urine studied by Levine and Fahy. The adjusted volume of urine is given in liters, as $liters_g$ or l_g.

$$\text{Adjusted volume} = \text{actual volume (liters)} \times \frac{\text{sp g} - 1.000}{0.024} = liters_g.$$

This was not the first time that the significance of the specific gravity of urine samples was discussed in this connection, but it was the first proposal to include measurement of this property as an integral part of the analysis, and to make its determination, in some cases, as important as that of lead itself.

The paper attracted a fair amount of interest among laboratories which carried out analyses of lead in urine, and a number adopted the procedure which was advocated. Others rejected this method, however, some on the ground that it was an unnecessary refinement, while others held that it was theoretically unsound.

Since the publication of Levine and Fahy's paper we have routinely used the specific gravity adjustment in calculating urinalysis results. Our laboratory analyzes, on the average, between 1,000 and 2,000 urine samples a year for heavy metals and solvent metabolites. In addition, during the past ten years we have been carrying out a study in which the results obtained with the specific gravity adjustment have been critically compared with those using other means of expressing urine concentration.

Table 2.—*Excretion and Body Size*

BSA, Sq m	$Liters_g$ per 24 hr (av)	
	M	F
1.44	...	0.68
1.56	0.68	0.69
1.65	0.79	0.63
1.75	0.91	0.65
1.84	0.89	0.71
1.94	0.98	0.85
2.04	0.99	...
2.13	1.05	...
2.26	1.17	...

As a result of this experience we have been able to draw the following conclusions relative to the specific gravity adjustment, and specifically relative to the merits and implications of Levine and Fahy's paper:

1. The adjustment should not be limited to analysis for lead. Levine and Fahy confined themselves to this metal, probably because most of their data related to lead analyses. Their reasoning would apply equally well to mercury, arsenic, thallium, selenium, and fluoride, and probably metabolites of organic solvents. It would also be applicable to most radioactive isotopes, but these were of little importance at the time of Levine and Fahy's paper. It would also seem logical to apply the adjustment in the quantitative determination of coproporphyrin, δ-amino-levulinic acid and other similar products.

As a matter of fact, Goldwater, in 1936, found some correlation between the specific gravity of urine and its silica content.[2]

2. The specific gravity must be accurately measured and expressed in relation to that of water *at the same temperature* as the urine sample. If the specific gravity of the urine is related to that of water at 4 C, as is frequently done, the adjustment will result in too high a value, particularly with dilute samples as shown in Table 1.

If a urinometer calibrated against water at 4 C is used, a suitable correction should be made before employing the specific gravity adjustment.

3. In the vast majority of cases, adjusted values are more consistent than actual concentration values. This is particularly true when some of the samples are dilute. This superiority is evidenced by consistently lower average deviations from the mean, among groups of samples from workers with similar exposures, or consecutive samples

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Table. 3—*Adjusted Daily Urine Volume and Diet*

Subject	BSA, Sq m	Liters$_g$ per 24 hr	
		Low-Protein	High-Protein
D	1.67	0.47	0.98
M	1.92	0.69	1.07

Table 4.—*Diet and Specific Gravity-Adjusted Concentration*

Subject	Diet	Contaminant Excreted (Hypothetical)	
		mg/24 hr	mg/liter$_g$
D	Low-protein	0.20	0.43
	High-protein	0.20	0.20

from the same individuals, when adjusted rather than unadjusted values are used.

4. In comparison with 24-hour or shorter timed samples, the specific gravity adjustment has the great practical advantage of eliminating dependence on the intelligence and reliability of the subject. One or both of these qualities are lacking in many workers; even under the most favorable circumstances, short of confinement to a hospital bed, we have found it very difficult to obtain reliable timed samples from workers, including supervisors and skilled technicians.

5. There are a number of factors which will affect the rate of excretion of various solid components of urine, and, thereby, the specific gravity-adjusted volume of urine voided in a given time. We have enough data and information to warrant further discussion of four of these factors, particularly as they affect the interpretation of urinalysis results.

(a) Body Size.—It would appear axiomatic that, other things being equal, size would show a positive correlation with rate of excretion; that is, a large man will, on the average, excrete more urine (adjusted or unadjusted) per day than a small man. For many purposes body surface area (BSA) is considered preferable to weight as an index of body size. Body surface area can be calculated approximately by means of a formula involving both height and weight, and we have used this method of estimating size.

According to our data, the rate of excretion of total solids, as evidenced by the daily voidance of urine—adjusted to specific gravity 1.024—does show a statistical relationship to BSA. Table 2 lists the average values for male and female workers, classified in some nine different size groups. The excretion rates are, for the most part, projected from timed samples of six to ten hours' duration, but include a number of actual 24-hour samples. No marked differences were found between the two types of samples, but the "actual" values were, on the average, slightly lower than the "projected" values.[3]

It is seen that the average rate of excretion of the largest size group (average weight, 103.4 kg [229 lb]) is not quite twice that of the smallest (53.5 kg [119 lb]).

If we accept the logical premise that rate of breathing and harmful dose are also related to BSA, it would follow that the rate of excretion of a toxic substance must be corrected for body size before it can be an accurate index of the hazard.

Table 5.—*Comparison of Dilute and Concentrated Sweating Sample Results*

Subject	Dilute					Concentrated				
	Sp G	Creatinine, gm/liter	Lead Found			Sp G	Creatinine, gm/liter	Lead Found		
			mg/liter	mg/24 hr	mg/liters$_g$			mg/liter	mg/24 hr	mg/liters$_g$
L*	1.022	1.60	0.20	0.24	0.22	1.026	3.05	0.24	0.15	0.22
W*	1.018	1.60	0.29	0.45	0.39	1.028	2.40	0.38	0.34	0.32
R*	1.024	2.02	0.22	0.27	0.22	1.029	2.65	0.19	0.13	0.15
B†	1.022	1.84	0.40	0.35	0.45	1.037	5.48	0.87	0.29	0.61
Av	1.022	1.76	0.28	0.33	0.32	1.030	3.40	0.42	0.23	0.32

* Exercised in laboratory.
† Subjected to hot work at secondary smelter.

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Table 6.—*Effect of Sugar*

Sample*	Lead Found Using Adjustment for	
	SG	Creatinine
Normal	0.25	0.20
Normal	0.20	0.24
Normal	0.21	0.22
Normal	0.16	0.16
Sugar present	0.04	0.17

* From five coworkers.

Hence, as between the rate of excretion of a toxic substance and the specific gravity-adjusted concentration, the latter has the advantage that it is little affected by size.

(b) Diet.—It has long been known that the quantity of urea excreted in the urine is related to the protein content of the diet. The excretion of other solids also appears to be increased by a high-protein intake. Typical data from the literature are shown in Table 3.[4]

If diet does not affect the excretion (or absorption) of heavy metals, solvent metabolites, etc, and if the rate of excretion (corrected for body size) is a true index of absorption, the specific gravity adjustment will lead to error when applied to urine specimens from persons with varying diets, particularly with respect to protein content. Assuming a constant excretion rate of heavy metal for subject D of Table 3, the specific gravity-adjusted values would differ markedly when on the different diets, as shown in Table 4.[4] A sample taken on the low-protein diet would indicate twice as severe an exposure as that obtained on the diet rich in protein.

(c) Exercise and Sweat.—Loss of fluid, salt, and other solids in perspiration is normally accompanied by a reduction in urine volume, and also in the rate of excretion of total solids. During a period of heavy sweating the specific gravity-adjusted volume voided per hour may be as little as half that found under normal conditions. The question arises as to whether or not the excretions of heavy metals, radioactive isotopes, and solvent metabolites are similarly affected.

We have carried out a number of perspiration experiments on lead and mercury workers. In some cases meaningful results were not obtained. The findings in four cases which did seem significant are summarized in Table 5.

In three of the four cases, concentration of the urine sample is accompanied by an increase in the actual concentration of lead. This confirms the premise on which the specific gravity adjustment is based.

In every case, moreover, the excretion of lead per 24 hours is greater in the dilute than in the concentrated samples. This finding would be consistent with reabsorption of lead in the kidney tubules, and excretion of significant amounts in the sweat.

Loss of body fluid as sweat may exceed the amount excreted in urine over a period of several hours, by a factor of five to ten.[5] The composition of sweat approximates that of blood plasma for many ingredients. On the other hand, due to the fact that the volume of plasma filtered by the kidney in the course of a day is more than 100 times the volume of urine excreted, the concentration in the urine of those ingredients which are not reabsorbed in the kidney tubules, may exceed the plasma concentration by an equivalent amount.[6] In the case of such substances, the loss through the sweat would be relatively unimportant. On the other hand, the loss in perspiration of a substance such as salt, which is strongly reabsorbed in the kidney, may be as great or greater than the excretion in the urine.

(d) Samples Containing Sugar.—Occasionally urine specimens of high specific gravity have been found to contain large amounts of glucose. For such urines, the specific gravity is not a good index of "concentration." Determination of the osmolality or creatinine value usually reveals that the sample is dilute with respect to ingredients other than sugar. In such cases expression of results as "milligrams per liters$_g$," or even "milligrams per liter" may lead to erroneous conclusions.

In Table 6 the lead contents of urine from a number of grinders in a bronze foundry are listed. One of the men consistently excreted sugar, and the urine, while of high specific gravity, had a low creatinine concentration. When the lead contents of the samples were calculated, using the specific gravity adjustment, this man alone was found to have no significant exposure. However, if the results of the analyses are expressed using a creatinine adjustment (1 mg of lead per 2 gm of creatinine), the exposure

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of this individual is found comparable to that of his coworkers.

Data from samples known to contain sugar have been excluded from our statistical compilations (Table 2).

Maximum and Minimum Credible Excretions

It has been shown that three nonpathologic factors—body size, diet, and sweating, each may affect the rate of excretion of specific gravity-adjusted urine by a factor of approximately two. The maximum variation in rate of excretion, *due to these factors alone*, would be a ratio of approximately eight to one. That is to say, a small man (53.5 kg [120 lg]) on a low-protein diet, who is sweating profusely, could be expected to excrete total solids at approximately one eighth ($\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$) the rate of a large man (104.1 kg [230 lb]) who is on a high-protein diet and is not perspiring.

We have examined the individual values among approximately 600 timed samples, collected from some 400 workers, and selected the two with the highest and lowest "credible" excretions, respectively, in terms of liters$_g$ per day. The pertinent data are shown in Table 7. Since adequate supervision of sample collection was not provided in every case, we have rejected those samples which did not meet an arbitrary criterion of reliability, namely, a creatinine excretion within 25% of the average for the same size group as the worker.

A number of the timed samples collected indicated 24-hour excretions below 0.34 liter$_g$ but were rejected because of low creatinine values. The lowest value was 0.18 liter$_g$, with a projected creatinine excretion of 0.30 gm/day. A smaller number of results on the high side were also rejected. The highest value was 3.52 liters$_g$ per day, with a daily creatinine excretion of 6.5 gm.

In assembling the data for Table 2, values were generally rejected if the rate of creatinine excretion differed by more than 50% from the average for the same size group. In selecting "credible" excretions, however, the stricter criterion of not over 25% deviation from the mean was chosen.

The highest credible excretion was 2.39 liters$_g$ per day, projected from a 5½-hour sample from a 35-year-old foundry worker. His creatinine output, during the same period, was at a rate of 1.75 gm/day, compared with an average of 1.92 gm for workers with BSAs between 2.10 and 2.19 sq m.

The lowest credible excretion was 0.34 liters$_g$ per day, obtained from a 41-year-old chemist, who submitted a 24-hour sample. His creatinine excretion was 1.0 gm/day; the average for his size group (1.60 to 1.69 sq m) is 1.38 gm.

It is seen that the excretion of A, in terms of adjusted volume per 24 hours, exceeds that of Q by a factor of seven. This is surprisingly close to our theoretical value of eight, the maximum probable difference resulting only from variations in size, diet, and degree of perspiration among male workers. Subject A is much larger than Q, but we have no knowledge of the diets of these men. It appears unlikely, however, that Q, a scientist, was sweating heavily throughout the 24-hour period. Hence it is probable that factors other than those which we have considered are partly responsible for the marked differences in rate of excretion.

If the lead values are considered, each man would be considered mildly exposed on the basis of his specific gravity-adjusted value. If, on the other hand, the 24-hour excretions are considered, A would be well in the harmful exposure range, while Q would appear to have no significant exposure. Correction for body size does not alter the situation materially.

In Table 8 comparable data are given for two mercury workers. These men are of comparable size, but the 24-hour excretion of total solids (liters$_g$) was nearly four times greater for K than for W. As a result, the specific gravity-adjusted mercury value for W is greater than that of K by a factor of over four, in spite of the fact that the rates of mercury excretion (1 mg/24 hr) are approximately the same. If we considered only the specific gravity-adjusted values, we would conclude that W is harmfully exposed, but that the exposure of K is within safe limits. On the other hand, if we considered only the 24-hour excretions of mercury, our conclusion would be a borderline exposure (0.25 mg/day) for each man.

The data at hand do not enable us to decide which of the preceding interpreta-

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Table 7.—*Maximum and Minimum Credible Excretions*

Subject	A	Q
Height	6 ft 1 in	5 ft 4 in
Weight, lb	209	138
BSA, Sq m	2.19	1.67
Liters$_g$ per 24 hr	2.39	0.34
Creatinine per 24 hr (gm)	1.75	1.10
Lead		
mg/liter$_g$	0.13	0.10
mg/24 hr	0.31	0.03

Table 8.—*Excretions of Two Mercury Workers*

Subject	K	W
Height	5 ft 10 in	5 ft 10 in
Weight, lb	175	147
BSA, Sq m	1.97	1.83
Liters$_g$ per 24 hr	2.13	0.54
Creatinine per 24 hr (gm)	2.12	1.52
Mercury		
mg/liter$_g$	0.11	0.48
mg/24 hr	0.23	0.26

tions is the more valid, in either of these situations. Of the factors which we have considered, body size and sweating probably affect rate of excretion more than they influence concentration adjusted for specific gravity. On the other hand, normal variations in diet do not influence the rate of excretion of toxic substances, so far as is known, but they may affect the total solid content of the urine and thereby the specific gravity-adjusted values for many individual substances.

Formation and excretion of urine is a complicated process, and many unknown variables contribute to the total rate of excretion, as well as to the rates of excretion of many individual substances. In cases such as those given in Tables 7 and 8, a logical procedure would be to average the results obtained by the two methods of calculation.

The resulting value can be considered an exposure index for the hazard in question. In the above cases the lead exposure indices of A and Q would be 0.22 and 0.07, respectively; the mercury exposure indices of W and K would be 0.37 and 0.17.

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PHOTOSYNTHESIS

The general kinds of pollution that may enter a stream due to man's activities are suspended solids, toxic pollutants, organic pollutants, and heat. The most obvious effect of a suspended solids load is to reduce light penetration into the water. Light is important for the process of photosynthesis which produces oxygen and thus replaces the oxygen used by respiration. It has been shown that photosynthesis is usually more important than turbulence in generating oxygen for the aquatic ecosystem. However, this may vary depending upon circumstances. Our studies have shown that most organisms live in the photosynthetic zone. Therefore, if this photosynthetic zone is reduced, the area for species occupancy is also reduced for most animals.—Patrick, R.: Aquatic Communities and the Problems of Water Quality, *General Systems* 13:125-127, 1968.

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