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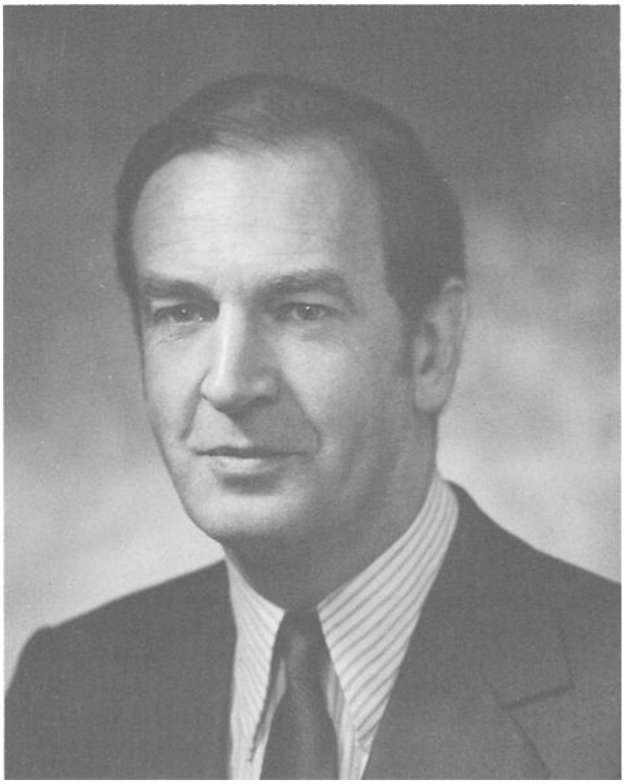
GUEST EDITORIAL



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Reporting Laboratory Data in the International System of Units

In several countries the SI (Système International des Unités) has become the accepted way for reporting data. This is particularly true in Europe where in several countries the system exclusively is used within hospitals for reporting data for patient-care purposes and for publication of scientific reports.

International communication of scientific information is obviously impeded as long as two independent and apparently unrelated systems of data reporting exist. Yet, when two systems are used to report data in any one country at the same time there is a tendency for people to think in terms of the old system, and not adjust at all to the new system. Consequently, when the old system is abolished, individuals who in theory should be familiar with the new system are not facile with it. To circumvent this situation arising in clinical practice most countries have adopted the policy of making a complete change to the new and preferred system on a specific date without a period of overlap.

Some professional societies in this country have already endorsed the SI while still recognizing the present impracticality of using it on a day-to-day basis. The SI is already used for reporting laboratory data in *Clinical Chemistry* and the *American Journal of Clinical Pathology.* It has been announced recently that publications of the College of American Pathologists will report data in SI units [*1*]. The *Journal of the American Medical Association* will shortly begin publication of laboratory data in SI as well as traditional units [*2*]. Système International units are already used in *Analytical Chemistry* [*3*].

Although it is still debatable whether SI units will replace traditional units in the clinical setting in the immediate future, I do believe that this is probable within a few years. It is already desirable that physicians become familiar with SI units so that they may understand foreign literature. If American publications do not publish data in SI units it is conceivable that major foreign discoveries will not be published in our journals. Likewise, the international impact of U.S. research and development will be lessened if the U.S. literature is not readily understandable outside this country. These are pressing reasons for initiating the practice of reporting data in both SI and traditional units in scientific journals even though SI units may not yet be used in clinical practice.

The Système International

The International Bureau of Weights and Measures is the body that has ultimate responsibility for international standardization of measurements. A series of conferences over several years has led to the development of the Système International, which has been accepted by the Bureau. The International System is based on the concept of seven dimensionally independent quantities for each of which a base unit, based on physical properties, can be defined with great accuracy. These base units are the reference points of the SI. Units for other properties are derived from these seven units. A coherent system of units is constructed in which all derived units are related to each other with an interconversion factor of unity, in the same way that the measured properties are derived from the seven fundamental properties. The base quantities, their units, and the abbreviations or symbols for these units are illustrated in Table 1.

The derivation of units is typified by the quantities derived from length, as shown in Table 2. For some of the complex units special names have been devised. Thus, for the unit of force—metre kilogram per second squared—the name newton is used. The unit for pressure—newton per square metre—is simplified as pascal.

If all values were related back to the base units some numbers would be very cumbersome. To avoid this, multiples and submultiples of the base units are used as required. The factors change by increments or decrements of 1000. For each of the units of the SI

TABLE 1—*Base quantities and units.*

Quantity	Base Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Thermodynamic temperature	kelvin	K
Light	candela	cd
Time	second	s
Electric current	ampere	A
Amount of substance	mole	mol

TABLE 2—*Derivation of compound SI units.*

Quantity	Derivation	Unit	Symbol
Length	base unit	metre	m
Area	length × length	square metre	m^2
Volume	length × length × length	cubic metre	m^3
Velocity	length per time	metre per second	$m\ s^{-1}$
Acceleration	velocity per time	metre per second squared	$m\ s^{-2}$
Force	mass × acceleration	metre kilogram per second squared or newton	$m\ kg\ s^{-2}$ or N
Pressure	force × area	newton per square metre or pascal	$N\ m^{-2}$ or Pa
Energy	force × length	newton metre or joule	N m or J

there are acceptable abbreviations, which must be adhered to if confusion is to be avoided. Thus, mg is the abbreviation for milligram, whereas Mg is the abbreviation for megagram (one thousand kilograms). The symbol is the same for single or plural values, and these are not followed by a period. They should be always written in Roman (upright) type. Rules for use of terms with the SI are very specific. Thus a prefix becomes part of a unit and only one prefix may be used per unit. Prefixes should be attached to a numerator of a compound derived unit. When prefixes are used with a numerator they should be chosen so that most values to be used with the unit fall between 0.1 and 1000. The decimal sign between numbers is indicated by a period. The comma, traditionally used to divide large numbers into groups of three, is replaced by a space. In compound units, a space should be left between symbols, or a dot may be inserted, to indicate a multiplication. Where a division is involved the negative index should be used except when the divisor is time, in which case a solidus (/) should be used. Thus concentrations should be expressed as mol l^{-1}, but a clearance is expressed as mol/s.

Implications of SI for Medicine

For application of the SI in medicine there are two important considerations that alter the apparent concentrations of constituents of body fluids. First, the unit of volume, to which all concentrations are referred, is the litre even though the correctly derived SI unit is the cubic metre. The cubic metre is about 400 times the blood volume in an adult, and it has been accepted that such a large unit is inappropriate as a reference unit in the clinical laboratory field. For clinical laboratory practice it has been accepted that the litre (cubic decimetre) is the appropriate unit to use even though it does not conform to the logical derivation of the SI. Replacement of the traditional reference unit of volume of 100 ml, or decilitre, by the litre would not pose many problems for the interpretation of data as laboratory data would be ten times as large as the values with which physicians are now familiar.

Second, the biggest change imposed by the SI on the reporting of laboratory data is the use of the concept of amount of substance, instead of mass of substance, as the numerator term. Where the molecular mass of a compound is known it is used to determine the amount of substance, which is expressed in moles. Thus concentrations are expressed in moles per litre. Where the molecular mass is not known concentrations are listed as kilograms (or submultiples of this) per litre. Where there is a mixture of compounds such as proteins for which molecular masses are known but relative amounts often are not, mass concentration is the preferred way for expressing results.

The size of the numbers that will arise with use of the reporting of data in moles per litre will be quite different from those with which a physician is now familiar, except for monovalent electrolyte concentrations that are now reported in milliequivalents per litre.

A sodium value of 140 mEq/l is still 140 when expressed in mmol/l. However, a calcium concentration of 10.0 mg/100 ml or 5.00 mEq/l is 2.50 mmol/l. The glucose value of 100 mg/100 ml is 5.6 mmol/l, and a typical normal range for uric acid of 3.0 to 7.0 mg/100 ml is actually 0.18 to 0.42 mmol/l.

The International unit, which has been slowly gaining acceptance for reporting of enzyme activity measurements, is replaced by a new unit because the reference time for the International unit is the minute and not the second which the SI dictates. However, there is a constant relationship between the International unit (one micromole per minute) and the appropriate SI unit, the nanomole per second. This latter unit is also known as a nanokatal. One nanokatal is numerically 16.67 times as large as one International unit. The preferred term for describing enzyme activity in body fluids is catalytic concentration, and values are expressed either as kat l^{-1} or mol/s l^{-1} (or as appropriate subunits of these units).

For hematologic data the reference volume to use is the litre, as for chemical constituents. This necessitates reporting values as so many cells times 10^9 (in the case of leukocytes) or times 10^{12} per litre (for erythrocytes).

All temperature measurements are made in degrees Celsius—a different name for what was formerly the degree Centigrade. Even the abbreviation (°C) for the two terms is the same. The degree Celsius is the accepted temperature unit for use in clinical laboratory measurements although the base unit of the SI for thermodynamic temperature is the kelvin. The temperature interval for one kelvin and one degree Celsius is the same. Use of the SI for temperature measurements will cause no change in the magnitude of values reported.

Measurements of heat output, or food ingestion, instead of being reported in Calories (kilocalories) are reported in joules with the SI. Measurements of other properties are relatively little used in the clinical laboratory field but the units used are different, as indicated in Table 1, and the values that will be reported in terms of SI will be different from those with which a physician or laboratory scientist is now familiar.

Justification for Use of SI Units

The principal justification for the reporting of data in molar terms is that biological reactions take place on a molar, and not a mass, basis. Expressing all values in such terms allows the relative amounts of materials to be demonstrated much better than when mass terms are used. Thus, while the normal urinary excretion of taurine per day might be 121 mg and that of glycine only 96 mg, apparently indicating a greater excretion of the former, when these values are expressed in molar terms the excretion of glycine is 1280 μmol and that of taurine only 970 μmol.

The influence of the molecular mass of proteins on their apparent concentrations is illustrated for some examples in Table 3. While serum albumin concentrations are normally about 4 g/100 ml and serum uric acid concentration may occasionally be as high as 10 mg/100 ml, on a molar basis there are approximately equal amounts of these materials—about 0.6 mmol/l. Problems of binding of compounds to albumin and their competitive displacement by each other are understandable when the concentration of both the albumin and the bound compounds are expressed in like terms. Compounds as different as calcium, bilirubin, drugs, and sulfobromophthalein can all be considered in the same way. In Table 4 the influence of molecular mass on hormone concentrations is shown.

For many tests the variety of units used to report numerical values is such that the relationship between different compounds is obscured. The metabolism of glucose is more readily understood when its concentration and those of pyruvate and lactate are ex-

TABLE 3—*Influence of molecular mass on reported values of serum proteins.*

Protein	Normal Range, mg/100 ml	Molecular Mass	SI Normal Range, μmol/l
Albumin	3400-4500	66 000	515 - 682
Ceruloplasmin	15- 60	151 000	1.0 - 4.0
α_2-macroglobulin	150- 420	725 000	2.1 - 5.8
Transferrin	200- 320	76 000	26 - 42
Immunoglobulin M	60- 250	950 000	0.6 - 2.6
Plasminogen	15- 35	87 000	1.7 - 4.0
Fibrinogen	200- 450	340 000	5.9 - 13.2

TABLE 4—*Hormone concentrations in SI units.*

Compound	Molecular Mass	Traditional Units	SI Units
Growth hormone	21 500	0 to 8 ng/ml	0 to 370 pmol/l
Aldosterone	360	up to 20 ng/100 ml	up to 560 pmol/l
Cortisol	362	5 to 20 μg/100 ml	0.14 to 0.55 μmol/l
Corticotropin	4 540	up to 80 pg/ml	up to 18 pmol/l
Testosterone	288	300 to 1200 ng/100 ml	10 to 42 nmol/l
Progesterone	314	up to 100 ng/100 ml	up to 3.2 pmol/l
Triiodothyronine	651	80 to 170 ng/100 ml	1.2 to 2.6 nmol/l
Thyroxine (total)	777	4.7 to 11.1 μg/100 ml	60 to 145 nmol/l
Thyroxine (free)	777	1.0 to 2.3 ng/100 ml	13 to 30 pmol/l

pressed in molar units. Diabetic ketosis can be better understood when the concentrations of ketoacids can be expressed in the same terms as glucose. The contribution of these compounds to an increased serum osmolality may be readily calculated.

The SI simplifies the understanding of turnover of materials by making it relatively simple to equate quantities of related compounds or materials in different fluids. Thus, it is possible to link together iron in hemoglobin, and serum iron and bilirubin, with urinary and fecal bile pigments.

In most basic medical research situations measurements are already commonly reported in molecular units. Use of the same units in clinical situations would be advantageous. Not only would this eliminate an impediment between application of biochemical research to clinical medicine but it also could reduce what is often seen as the difference between clinical medicine and other scientific or research disciplines.

Disadvantages of the SI

In practice the SI introduces unfamiliarity into an area in which most physicians were previously familiar. They will no longer have the intuitive feel that certain data are normal, or slightly or grossly abnormal. Certain concepts such as osmolality are handled less well by the SI than by traditional reporting practice because the osmole is not an accepted SI term, and the units to use would differ depending on which technique was used, either the actual depression of the freezing point or the change in vapor pressure.

With the SI it is possible to report hydrogen ion concentration in terms of moles per litre, yet use of this would probably lessen understanding of changes in acid-base balance and invalidate many of the nomograms now used. Accordingly, pH is still regarded as an appropriate term and measurement.

In clinical laboratory practice it is difficult to conform to all the requirements of the SI. There are often limitations imposed by computers. Thus, it is usually impossible to print in lower case as well as in upper case and it is impossible to use subscripts and superscripts as the SI requires. Most laboratory computer systems are programmed to report data in one set of units only. A decision must then be made to use either traditional or SI units. A clinician must make the translation from one to the other by himself.

Several units are in daily use which do not conform to the SI. These include the International Units used to establish the potency of various biological preparations where the mass or purity of the protein is unknown and the various arbitrary units are often described by the name of the individual who first used them. When these are adequately defined, and no alternative unit is available, data can be reported with these units.

With a decision to implement SI units in a scientific publication, these should probably be considered the primary units. This is based on the assumption that these will ultimately be the only units used for reporting data. Data should then be listed first in SI units with traditional units in parentheses. All figures should include data in molar units in preference to the traditional units but tables, if small, should include the data in two columns, with the SI units first and traditional units second. If tables contain many columns values in SI units should be listed in preference to the same data in traditional units. A footnote including the conversion factor should be included.

Appropriate conversion factors to use have been included in the publications by Young [*4*] and Lehmann [*5*]. Several other compilations of conversion factors from traditional to SI units are already in use. Where conversion factors have not previously been published these may be calculated knowing that one mole is the molecular mass of a compound expressed in grams.

Considerable additional information on the SI is contained in publications that are readily available. The background is well covered in a monograph produced by the National Bureau of Standards [*6*]. Details of the derivation of units as they apply to clinical laboratory data have been discussed by Dybkaer [*7*], and Young has previously discussed the justification for using the system and problems of its implementation [*8*].

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