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Brief Communication

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Unit conversions between LOINC codes

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ABSTRACT

Logical Observation Identifiers Names and Codes (LOINC) is the most widely used controlled vocabulary to identify laboratory tests. A given laboratory test can often be reported in more than 1 unit of measure (eg, grams or moles), and LOINC defines unique codes for each unit. Consequently, an identical laboratory test performed by 2 different clinical laboratories may have different LOINC codes. The absence of unit conversions between compatible LOINC codes impedes data aggregation and analysis of laboratory results. To develop such conversions, a computational process was developed to review the LOINC standard for potential conversions, and multiple expert reviewers oversaw and finalized the conversion list. In all, 285 bidirectional conversions were identified, including conversions for routine clinical tests such as sodium, magnesium, and human immunodeficiency virus (HIV). Unit conversions were applied to the aggregation of laboratory test results to demonstrate their usefulness. Diverse informatics projects may benefit from the ability to interconvert compatible results.

Key words: LOINC, clinical laboratory information systems, controlled vocabulary

INTRODUCTION

The sinking of the Swedish warship Vasa, the crash landing of a Boeing 767 at Gimli Airpark, and the loss of the first interplanetary weather satellite, the Mars Climate Orbiter, have something in common.[1] They represent catastrophes due to improper conversions among different units of measurement. Similar examples exist in health care. For instance, the Institute of Safe Medication Practices reported a patient who received >15 times the prescribed dose of phenobarbital when a pharmacist dispensed 0.5 grams instead of the prescribed 0.5 grains.[2] Similar to medication dosing, interpreting clinical laboratory test results depends on an accurate understanding of units of measure, and inaccuracies have the potential to contribute to poor clinical outcomes.

Many analytes in the clinical laboratory have multiple units of measure in common use. Clinical laboratories in the United States, for example, report common electrolyte measurements such as calcium in either moles or mass. To account for differences in the reported unit, the most widely adopted controlled vocabulary for laboratory tests, Logical Observation Identifiers Names and Codes (LOINC), provides a separate code for each unit of measure.[3] For example, code 17864-0 measures calcium in units of mass while code 1995-0 uses molar units.[4,5]

Clinical decisions, laboratory test utilization studies, and epidemiological research all require a coherent view of laboratory data. Unfortunately, unit conversions between compatible LOINC codes have not been adequately and systematically developed. To overcome this limitation, we sought to create a standard set of conversions between common LOINC codes.

METHODS

The process of identifying candidate tests for unit conversion relied on a set of objective steps. We began with LOINC version 2.58, which we filtered to remove non-laboratory tests, tests not ranked in

the top 98% by frequency, and tests without units.[6] Next, we grouped together tests that measured similar analytes in similar specimens. For each group, we counted the number of unique units. Groups with only 1 unit were removed, since unit conversion requires at least 2 different units. Otherwise, we computed the 2-way combinations such that a group with 2 LOINC codes produced 1 candidate LOINC pair for unit conversion. Consequently, a group with 4 LOINC codes produced 6 candidate LOINC pairs (ie, 4 choose 2: AB, AC, AD, BC, BD, CD). Each combination underwent further manual review by 3 expert clinical pathologists.

While we accepted the LOINC definitions for terms such as "units" and "analytes" in most cases, there were a few notable exceptions. We merged LOINC specimens such as "blood" and "venous blood" into single higher-level clinically meaningful groups. This allowed codes associated with either "blood" or "venous blood" specimen types to exist in the same group. Additionally, we consolidated codes with like analytes into the same group. For example, codes measuring "albumin µg/min" were grouped together with "albumin" such that similar tests could be analyzed together. Finally, we added a conversion between the ratio of high-density lipoprotein (HDL) to total cholesterol and its reciprocal (LOINC codes 2095-8 and 9830-1). The algorithm we developed to screen for potentially convertible units is detailed in the Supplementary Data and accessible in an open-source code repository.[7]

Next, 3 board-certified clinical pathologists manually reviewed all candidate pairs for unit interconversion. LOINC pairs identified as compatible by the reviewers were appropriately interconverted and cited. Documentation of the calculations for each unit conversion can be found in the Supplementary Data, which also contains citations to primary literature for nontrivial conversions such as the conversion of ethanol measured in blood to ethanol in serum/plasma. We believed explicit documentation of our calculations was necessary after numerous online calculators, most notably the one in the American Medical Association Manual of Style, proved imprecise. For example, the conversion of 1 kilogram to pounds is listed as 2.22, when the true number is 2.20.[8] The expert reviewers verified the final list of conversions.

To demonstrate the effect of unit conversion, we compared laboratory results for calcium reported in mass to those results reported in moles. Specifically, we selected 10 000 laboratory results for LOINC codes 17864-0 and 1995-0 from the Veterans Health Administration (VA) database. Outliers >2.5 standard deviations from the mean were removed, along with results reported with incorrect units relative to their assigned LOINC code. We plotted the distribution of results before and after conversion to a common unit (mg/dL). We repeated the process for a second test, ammonia, with LOINC codes 16362-6 and 22763-7, except in this case we did not remove data with incorrect LOINC code assignments.

RESULTS

Beginning with 2398 LOINC codes for common laboratory tests, the screen process progressively selected for 285 pairs of interconvertible codes. The screen process removed codes without a unit ($n = 884$) followed by codes without a second code to pair together for a unit conversion ($n = 1070$). Expert review of the remaining codes identified 285 bidirectional unit conversions between common LOINC codes. When grouped by conversion type, 250 codes represented a mass-to-mole conversion (eg, moles to grams), 22 involved metric-to-metric conversions (eg, deciliters to liters), 10 rescaled a count (eg, per microliter vs 1000 per microliter; linear vs log scale), 2 conversions involved a synonym for an existing unit (ie, Ehrlich unit), and 1 conversion involved an inverse (ie, HDL/total cholesterol). A sample list of conversions can be seen in Table 1.

In the process of conversion selection and creation, certain topics generated discussion among the reviewers, and users of these conversions may have different opinions. Box 1 contains a list of these topics.

Figure 1 shows the distribution of laboratory results for 2 ammonia LOINC codes measured in either micrograms per deciliter (LOINC 22763-7) or micromoles per liter (LOINC 16362-6). Applying a unit conversion to LOINC 16362-6 converts its test results from micromoles per liter to micrograms per deciliter. The 2 distributions then converge.

A separate example with calcium demonstrates a similar, yet distinct, phenomenon (Figure 2). As in the ammonia example, 2 LOINC codes for calcium utilize different units of measure. The majority of their results converge into a single distribution when the units of the first LOINC code, millimoles per liter, are converted to the units of the second, milligrams per deciliter. Unlike the prior example, however, we did not remove laboratory results from incorrectly assigned LOINC codes. Consequently, we see that some test results for the second LOINC code were reported in the units expected for the first LOINC code. The presence of 2 units of measure in the LOINC code yields a second peak in the distribution that does not correct with unit conversion (see Figure 2, arrow).

DISCUSSION

Diverse informatics projects benefit from the ability to interconvert similar laboratory results with different units of measurement. In the domain of laboratory test utilization, studies increasingly rely on computer-facilitated integration and analysis.[15] The added ability to convert between compatible units permits utilization reviews across a larger segment of a health care system. For example, the ability to interconvert between calcium measured in milligrams per deciliter and millimoles per liter permits benchmark comparisons between these otherwise separate populations. A health information exchange or multinational research data repository with measurements in the metric and imperial systems has a similar need for unit interchange.

The appropriate unit conversion depends on satisfying basic assumptions. First, LOINC codes must be correctly assigned to the laboratory tests performed by each clinical laboratory. In theory, such a statement appears obvious, but in practice, LOINC contains tens of thousands of laboratory test codes. The selection of LOINC codes often requires specific domain expertise and institutional choices. For example, hemoglobin has 4 commonly used codes, which may or may not specify the test performance method. Such nuances make it difficult to choose the correct code, even after consulting the LOINC User's Guide,[16] as we witnessed in our example of calcium, which contained incorrectly assigned LOINC codes. Other authors have reported similar challenges.[17]

Second, LOINC may not specify the unit most commonly used in clinical practice. Lithium, for example, has units of moles per liter documented under code 14334-7 in the column titled "Example UCUM Units."[18] The clinical laboratories in our health care system have never, to our knowledge, reported lithium in these units. Our laboratories, major manufacturers of the lithium test reagents, and reference laboratories prefer the unit of millimoles per liter.[19–22]

With specific knowledge of laboratory operations, additional conversions may exist. For example, Roche, a manufacturer of HIV

Table 1. Unit conversions between LOINC codes

LOINC 1	LOINC 2	Name 1	Name 2	Unit 1	Unit 2	Conversion
22763-7	16362-6	Ammonia [Mass/volume] in Plasma	Ammonia [Moles/volume] in Plasma	µg/dL	µmol/L	[16362-6] = [22763-7]/1.703
1995-0	17864-0	Calcium.ionized [Moles/volume] in Serum or Plasma	Calcium.ionized [Mass/volume] in Serum or Plasma by ISE	mmol/L	mg/dL	[17864-0] = [1995-0]*4.008
31019-3	48348-7	10-Hydroxycarbazepine [Mass/volume] in Serum or Plasma	10-Hydroxycarbazepine [Moles/volume] in Serum or Plasma	µg/mL	µmol/L	[48348-7] = [31019-3]*(10/2.543)
3298-7	70198-7	Acetaminophen [Mass/volume] in Serum or Plasma	Acetaminophen [Moles/volume] in Serum or Plasma by Screen Method	µg/mL	µmol/L	[70198-7] = [3298-7]*(10/1.512)
14586-2	1763-2	Aldosterone [Moles/volume] in Serum or Plasma	Aldosterone [Mass/volume] in Serum or Plasma	pmol/L	ng/dL	[1763-2] = [14586-2]*0.03605
1952-1	14626-6	Beta-2-Microglobulin [Mass/volume] in Serum or Plasma	Beta-2-Microglobulin [Moles/volume] in Serum	µg/mL	nmol/L	[14626-6] = [1952-1]*0.0118
14629-0	1968-7	Bilirubin.direct [Moles/volume] in Serum or Plasma	Bilirubin.direct [Mass/volume] in Serum or Plasma	µmol/L	mg/dL	[1968-7] = [14629-0]*0.05847
14633-2	1986-9	C peptide [Moles/volume] in Serum or Plasma	C peptide [Mass/volume] in Serum or Plasma	pmol/L	ng/mL	[1986-9] = [14633-2]*0.00302
25361-7	3422-3	Caffeine [Moles/volume] in Serum or Plasma	Caffeine [Mass/volume] in Serum or Plasma	µmol/L	µg/mL	[3422-3] = [25361-7]*0.1942
18262-6	69419-0	Cholesterol in LDL [Mass/volume] in Serum or Plasma by Direct Assay	Cholesterol in LDL [Moles/volume] in Serum or Plasma by Direct Assay	mg/dL	mmol/L	[69419-0] = [18262-6]/38.67

Documentation of the calculations for each unit conversion can be found in the Supplementary Data.

Box 1. Topics of discussion

1. Interconvertible Specimen Types

(A) Dried Blood Spot

Conversions between dried blood spot specimens and other specimen types (whole blood, serum, plasma) were not included. In general, dried blood spot specimens appear to have a weak correlation to serum or plasma.[9] In future versions of LOINC, specific conversions between dried blood spots and other specimen types may have better correlations.

(B) Saliva

Cortisol measured in saliva appears to have a weak correlation with cortisol measured in serum/plasma.[10] This led to the exclusion of certain conversions (14675-3 and 2142-8).

(C) Blood and Serum/Plasma

Measurements in whole blood can be converted to measurements taken in serum or plasma. In many cases, whole blood measurements come from point-of-care devices. The manufacturers of the devices simplify interpretation of their results by normalizing them to serum/plasma specimens. Thus, results in whole blood for glucose, creatinine, and triglyceride are well correlated with measurements in serum/plasma and can be interconverted.[11–13] Other analytes, notably ethanol, do not calibrate whole blood results to those of serum/plasma. As a consequence, an additional conversion factor is needed to account for ethanol's higher solubility in serum/plasma as compared to whole blood.

2. Molecular Weight

(A) Molecular Weight of Biological Salts

Conversions for biological salts relied on the molecular weight of the parent molecule rather than the weight of both molecules in the salt. For example, the molecular weight for calcium includes only the cation, Ca^{2++}, rather than calcium chloride. This practice generally corresponded with the molecular weight used in the conversion provided by the manufacturer of the test.

(B) Dependency of Molecular Weight on pH

Many biological molecules have pKa values near the biological pH of human blood. Thus, fluctuations in pH can change the molecular weight of the compound. The molecular weights listed in PubChem, the National Institutes of Health's library of chemical compounds, matched the conversion provided by the manufacturer of the laboratory test in nearly all cases. Consequently, molecular weights found in PubChem were not changed. Furthermore, the weight of 1 or more protons represents a small proportion of the molecular weight for most biological molecules.

3. Mixed Molecules

Certain tests detect a mixture of molecules, which makes determination of a specific molecular weight difficult. In most cases, the molecular weight of the molecules in the mixture demonstrate wide variation: barbiturates, benzodiazepines, and ketones. Although these conversions were omitted for this reason, manufacturer-specific conversions may be available in the package insert. One family of mixed molecules, the estrogens, were included due to the similar molecular weight between estrogen's major molecules: estrone (270.4 Da), estradiol (272.4 Da), and estriol (288.4 Da).

4. Empirical Relationships

Conversions made possible by curve-fitting to experimental data were not included in the conversion list, because they may apply only to select populations and vary between research studies. For example, plasma lead levels demonstrated a curvilinear relationship with whole blood lead levels among a cohort of women.[14]

5. Limit of Detection

LOINC has supplied unique codes to distinguish between the various limits of detection for molecules like testosterone and thyrotropin. Although we did not distinguish between tests based on their limits of detection, conversions at the lower limit of the scale for tests with different limits of detection may require careful interpretation.

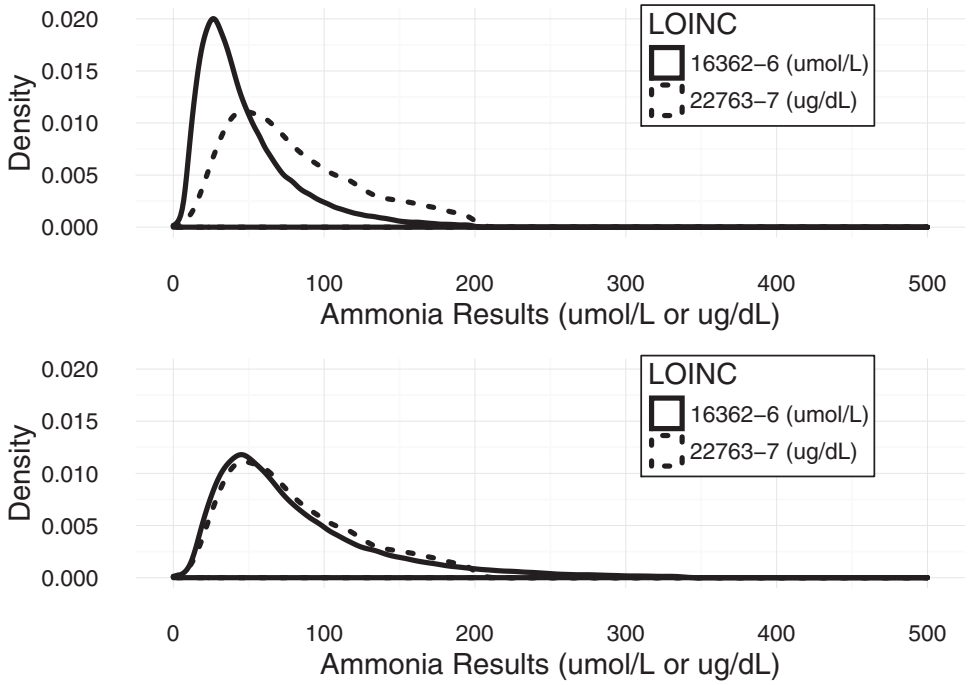

Figure 1. Ammonia results reported in either micromoles per liter or micrograms per deciliter (top) then converted to a single unit, micrograms per deciliter (bottom).

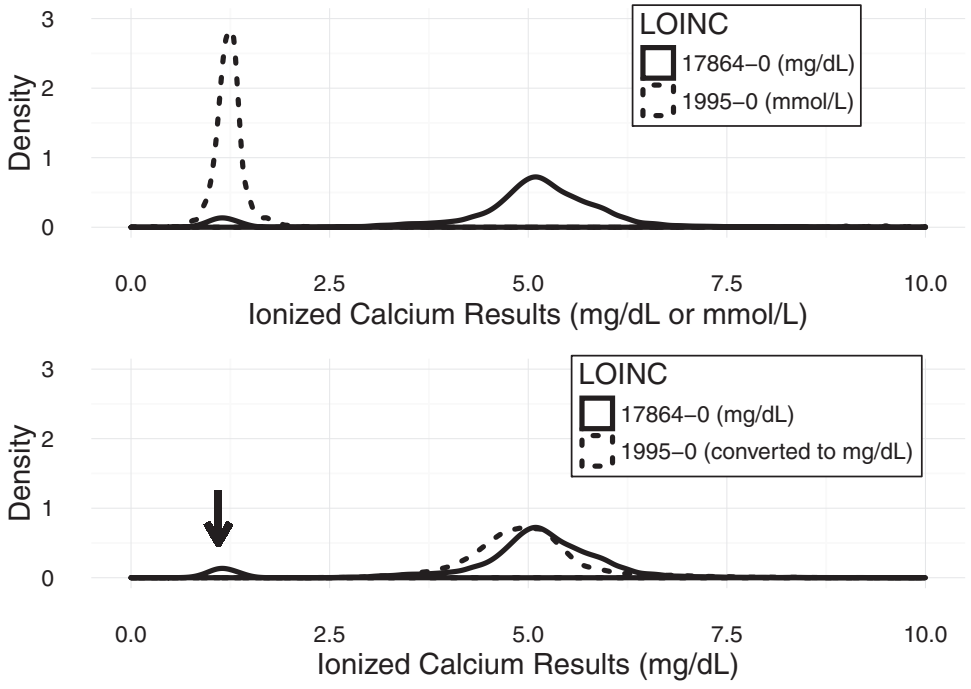

Figure 2. Ionized calcium results reported in either milligrams per deciliter or millimoles per liter (top) then converted to a single unit, milligrams per deciliter (bottom). The arrow indicates laboratory test results erroneously reported in millimoles per liter instead of the expected units of milligrams per deciliter.

viral load tests, claims that 1 copy of HIV-1 RNA from its assay is equivalent to 1.67 international units.[23] We did not adopt manufacturer-specific test conversions, because LOINC does not supply manufacturer-specific codes. Hence, our conversion between 2 LOINC codes must apply to all test manufacturers. Information systems without a strict adherence to LOINC may choose to adopt manufacturer-specific conversions as well as adapt our conversion to their own test identification vocabulary.

A health care system should standardize results reporting to preferred units when feasible, rather than allow individual laboratories

within the system to choose the units of test results. Standardized units aid clinicians who view health records of patients who visit multiple facilities within the system. Poorly communicated changes to the units of laboratory tests could also have detrimental effects. For instance, laboratories commonly report salicylate levels (eg, aspirin) in either milligram per deciliter or milligram per liter.[24] Misinterpreting the salicylate level could underestimate or overestimate the severity of salicylate intoxication.

The correct reporting and interpretation of laboratory test units of measure represents an important aspect of clinical data in both patient care and informatics applications. We developed a set of unit conversions relative to the LOINC standard for test identifiers. To optimize the usefulness of these conversions, laboratories should assign LOINC codes consistent with the units reported in their test results, and curators of LOINC should verify that the unit associated with each code reflects actual clinical practice.

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COMPETING INTERESTS

The authors have no competing interests to declare.

CONTRIBUTIONS

RGH and DBQ contributed equally to concept development, implementation, and manuscript preparation. AR and SC reviewed the conversions and edited the manuscript.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Journal of the American Medical Informatics Association* online.

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