

Effect of Protein on Hemoglobin and Hematocrit Assays with a Conductivity-Based Point-of-Care Testing Device: Comparison with Optical Methods

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Abstract. Point-of-care testing (POCT) for blood hemoglobin and hematocrit (H/H) levels provides rapid patient assessment including the need for transfusion. Conductivity-based methods of blood H/H determinations can be influenced by plasma protein concentration. To assess this factor, we measured H/H levels at varying protein concentrations using two POCT instruments: iSTAT-1 (conductivity method) and Hemocue (optical method). These H/H results were compared to results obtained by our core laboratory hematology analyzer (GenS). Anticoagulated whole blood was centrifuged to sediment the red blood cells; the plasma was removed to serve as source of protein for mixing studies. A series of reconstituted samples was prepared with varying H/H and protein levels. To mimic hemodilution in clinical practice, samples were diluted with saline or lactated Ringer's solutions. Following H/H analysis, the samples were centrifuged and protein determined in the supernatant plasmas. The H/H results obtained with the Hemocue instrument correlated exactly with those of the GenS analyzer at protein concentrations from 0.7 to 6.2 g/dl. The correlation was unaffected when hemodilution was performed with either saline ($r = 0.999$) or lactated Ringer's ($r = 1.000$). The H/H results obtained with the iSTAT-1 instrument gave slightly less correlation with those of the GenS analyzer ($r = 0.978 - 0.980$) over this protein range. However, the iSTAT-1 results were generally lower than the GenS results, with discrepancies up to 2 g/dL for hemoglobin values and up to 4% for hematocrits at the lowest protein concentration. Therefore, it is recommended that H/H testing in patients with suspected hypoproteinemia or substantial hemodilution should be tested with a non-conductivity-based method. (received 19 May 2003; accepted 20 September 2003)

Keywords: point-of-care-testing, blood conductivity, hemoglobin, hematocrit

Introduction

Numerous point-of-care testing (POCT) devices are currently available [1-3] that provide blood hemoglobin and hematocrit (H/H) determinations to assist in rapid patient assessment, including the need for blood transfusion [4-6]. Although the POCT devices use various methods [4,7-9], the conductivity-based procedures for blood H/H determinations can be influenced by plasma composition, including electrolyte and protein concentrations [4,5,10,11]. The iSTAT-1 POCT

device uses conductivity to estimate the hematocrit of whole blood samples and calculates the hemoglobin concentration by a simple equation [12]. This instrument has been the subject of several studies to evaluate its accuracy [4,11], especially in patients undergoing significant hemodilution, eg, during cardiopulmonary bypass surgery [5,10,12]. The studies showed that variations in plasma composition can substantially influence the H/H results, with plasma protein having the greatest effect [5,10]. These studies analyzed actual patient blood samples with few data points at the extremes of H/H and protein levels that are found in critically ill neonatal and adult populations [11,13,14].

To assess this problem more systematically, we generated a series of reconstituted whole blood samples with varying H/H levels and plasma protein

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concentrations. The reconstituted samples were assayed for H/H using two POCT instruments that are used at our institution: iSTAT-1 (conductivity method) and Hemocue (optical method). The H/H results obtained by these POCT devices were compared to those obtained by use of the GenS hematology analyzer that is the primary method in our core clinical laboratory.

Materials and Methods

This protocol was approved by the Institutional Review Board, Office of Research Compliance, of the University of Connecticut Health Center (IRB #03-099). All materials and procedures for point-of-care testing (POCT) were obtained from the manufacturers and were used according to the manufacturers' directions. Saline (NaCl, 9 g/L) and lactated Ringer's solutions were obtained from Baxter Healthcare (Deerfield, IL). Lithium-heparin Vacutainer tubes were obtained from Becton-Dickinson (Franklin Lakes, NJ).

The iSTAT-1 POCT device (Model iSTAT-1 with EC6+ cartridges, I-STAT Corp., Princeton, NJ) uses a conductivity-based method to measure blood hematocrit [12]. Briefly, whole blood is introduced by capillary action into a single-use microfabricated biosensor cartridge. After correction for electrolyte concentration, the measured conductivity is inversely related to the blood hematocrit. Blood hemoglobin concentration is calculated by the following equation: hemoglobin (g/dl) = hematocrit (decimal fraction) x 34.

The Hemocue POCT device (Hemocue AB, Angelholm, Sweden) measures hemoglobin by an optical-based method [15]. Briefly, whole blood is introduced by capillary action into a single use cuvette and sodium deoxycholate is added to lyse the red blood cells (RBC). The hemoglobin that is released is converted by sodium nitrite to methemoglobin, which together with sodium azide generates azide methemoglobin. The absorbance of the sample is measured at dual wavelengths: 570 nm to determine methemoglobin and 880 nm to compensate for sample turbidity.

The GenS analyzer (Beckman-Coulter, Inc., Brea, CA) counts and sizes cells by detecting and

measuring changes in electrical resistance when particles (eg, blood cells) in a conductive liquid pass through a small aperture [16]. The blood hematocrit is calculated from the RBC count and the mean corpuscular volume (MCV), using the following equation: hematocrit (%) = (RBC x MCV)/10. The blood hemoglobin concentration is determined optically following RBC lysis, based on transmittance measurements (%T) using the following equation: hemoglobin (g/dl) = constant x log₁₀(reference %T/sample %T).

Quality control of the iSTAT-1 instrument was performed using an electronic quality control simulator provided by the manufacturer. Quality control for hemoglobin assays with the Hemocue instrument was performed using 3 levels of Glu/Hgb whole blood controls (R&D Systems, Inc, Minneapolis, MN) with the following acceptable values (mean±SD): 5.2±0.3 g/dl (level 1); 12.6±0.4 g/dl (level 2); and 15.6±0.6 g/dl (level 3).

Quality control of the GenS hematology analyzer was performed every 8 hr using 3 levels of Coulter 5C cell controls (Coulter Corp., Miami, FL) with the following acceptable values (mean±SD): 5.04±0.06 g/dl (level 1); 12.9±0.08 g/dl (level 2); and 16.03±0.09 g/dl (level 3) for hemoglobin; and 15.1±0.2% (level 1); 37.4±0.4% (level 2); and 48.6±0.5% (level 3) for hematocrit.

Sample preparation. Blood samples were obtained from human volunteers who gave informed consent under the tenets of the Declaration of Helsinki. Whole blood was obtained by venipuncture into Vacutainer tubes with lithium-heparin anticoagulant and immediately centrifuged in a bench-top centrifuge (Model CR412, Jouan, Inc., Winchester, VA) at 3,200 rpm for 10 min at room temperature. The supernatant plasmas, which were removed and transferred to a 50 ml conical polypropylene tube, served as a pooled source of protein for sample reconstitution studies. Following addition of approximately two volumes of 0.9% saline, the RBC pellets were transferred to and pooled in 50 ml conical polypropylene tubes. The RBCs were gently resuspended by inversion (3 to 4 times) and then centrifuged at 1,000 rpm for 10 min at room temperature. Following removal of the wash

solution, the RBC pellets were gently inverted several times to form homogeneous RBC suspensions. The hemoglobin concentration (eg, 27.5 g/dl) and hematocrit (eg, 79.6%) of the RBC suspension were measured with the GenS hematology analyzer and the protein concentration (eg, 7.5 g/dl) of the pooled plasma was measured using a Model LXi clinical chemistry analyzer (Beckman-Coulter, Inc) [17] in our core laboratory. Based on the H/H and protein results, reconstituted samples with varying H/H and protein levels were generated (Table 1). To mimic the hemodilution that occurs in clinical practice, the reconstituted samples were diluted with either saline or lactated Ringer's solutions. A final volume

of 2 ml for each reconstituted sample was sufficient for the subsequent analyses on the POCT and core laboratory instruments.

Sample analysis. The reconstituted samples were analyzed in the following order: iSTAT-1 (hematocrit and calculated hemoglobin), Hemocue (hemoglobin), and GenS (hematocrit and hemoglobin). The reconstituted samples were then centrifuged at 3,200 rpm for 10 min at room temperature to pellet RBCs; the supernatant was removed and analyzed for protein with the model LXi clinical chemistry analyzer (Beckman-Coulter, Inc) [17]. Each sample was analyzed once on each instrument.

Table 1. Sample reconstitution design.

Group No	Tube No	RBCs (ml)	Plasma (ml)	Saline or Ringer's (ml)
1	1	1.2	0.8	0.0
	2	1.2	0.6	0.2
	3	1.2	0.4	0.4
	4	1.2	0.2	0.6
	5	1.2	0.1	0.7
2	6	0.9	0.8	0.3
	7	0.9	0.6	0.5
	8	0.9	0.4	0.7
	9	0.9	0.2	0.9
	10	0.9	0.1	1.0
3	11	0.6	1.0	0.4
	12	0.6	0.8	0.6
	13	0.6	0.6	0.8
	14	0.6	0.4	1.0
	15	0.6	0.2	1.2
4	16	0.5	1.0	0.5
	17	0.5	0.8	0.7
	18	0.5	0.6	0.9
	19	0.5	0.4	1.1
	20	0.5	0.2	1.3
5	21	0.4	1.0	0.6
	22	0.4	0.8	0.8
	23	0.4	0.6	1.0
	24	0.4	0.4	1.2
	25	0.4	0.2	1.4
6	26	0.3	1.0	0.7
	27	0.3	0.8	0.9
	28	0.3	0.6	1.1
	29	0.3	0.4	1.3
	30	0.3	0.2	1.5

Data analysis. Paired data sets were evaluated by least squares linear regression, correlation coefficient, and Bland-Altman analysis [18]. The linear regression analyses used Cricket Graph version 1.3.2 (Cricket Software, Inc, Malvern, PA). The correlation coefficient was classified as "very high" ($r = 0.9-1.00$), "high" ($r = 0.70-0.89$), "moderate" ($r = 0.50-0.69$), "low" ($0.30-0.49$), "little, if any" ($0.00-0.29$), based on Westgard's recommendations [19]. Bland-Altman analysis used MedCalc software version 7.2.0 (MedCalc, Inc, Mariakerke, Belgium). The limit of agreement (LOA) was calculated from the analytical bias ± 1.96 times the SD.

Results

Hemoglobin and hematocrit results obtained with the two POCT instruments and the GenS analyzer (primary method) and the protein concentrations of the samples are listed in Tables 2 and 3. The hemoglobin results obtained with the Hemocue POCT instrument were very close to those of the primary method over the broad range of protein concentrations and hematocrit levels. The hemoglobin results obtained with the Hemocue instrument were generally unaffected by the hemodilution with either saline or Ringer's solution.

In contrast, H/H results obtained with the iSTAT-1 POCT instrument were progressively discrepant from the primary method at low protein concentrations and low hematocrit levels. Sample discrepancies up to 2 g/dl for hemoglobin and up

Table 2. Comparison of hemoglobin and hematocrit results (saline diluent).

Tube	iSTAT-1 Hct (%)	iSTAT-1 Hb (g/dl)	GenS Hct (%)	GenS Hb (g/dl)	Hemocue Hb (g/dl)	Protein (g/dl)	iSTAT – GenS Hct (%)	iSTAT – GenS Hb (g/dl)
1	51	17	48.2	17.1	17.5	6.5	2.8	-0.1
2	50	17	47.8	17.0	17.5	5.0	2.2	0.0
3	50	17	48.3	17.2	17.7	3.5	1.7	-0.2
4	48	16	48.5	17.1	17.6	2.0	-0.5	-1.1
5	46	16	48.4	17.3	17.6	1.1	-2.4	-1.3
6	34	12	33.7	12.1	12.8	5.2	0.3	-0.1
7	35	12	35.4	12.7	13.0	4.0	-0.4	-0.7
8	36	12	36.5	13.0	13.4	2.8	-0.5	-1.0
9	33	11	36.1	13.0	13.4	1.5	-3.1	-2.0
10	33	11	36.6	13.0	13.3	0.8	-3.6	-2.0
11	24	8	23.9	8.5	9.0	5.2	0.1	-0.5
12	24	8	24.8	8.9	9.3	4.2	-0.8	-0.9
13	22	7	23.9	8.7	9.0	3.1	-1.9	-1.7
14	22	7	24.8	8.8	9.1	2.2	-2.8	-1.8
15	20	7	24.6	8.7	9.1	1.1	-4.6	-1.7
16	21	7	19.3	7.0	7.4	5.0	1.7	0.0
17	18	6	20.1	7.2	7.4	4.1	-2.1	-1.2
18	17	6	20.3	7.3	7.5	3.1	-3.3	-1.3
19	17	6	20.6	7.3	7.6	2.0	-3.6	-1.3
20	15	5	20.9	7.3	7.6	1.1	-5.9	-2.3
21	16	5	15.8	5.7	6.0	4.8	0.2	-0.7
22	15	5	15.6	5.6	5.9	3.8	-0.6	-0.6
23	13	<	16.1	5.8	6.2	2.8	-3.1	nc
24	13	<	16.5	5.9	6.1	2.0	-3.5	nc
25	13	<	16.9	6.0	6.4	0.9	-3.9	nc
26	11	<	11.5	4.3	4.4	4.5	-0.5	nc
27	10	<	11.4	4.2	4.4	3.6	-1.4	nc
28	10	<	12.1	4.4	4.6	2.8	-2.1	nc
29	<10	<	11.9	4.3	4.5	1.8	nc	nc
30	<10	<	12.8	4.6	4.8	0.8	nc	nc

Table 3. Comparison of hemoglobin and hematocrit results (Ringer's solution diluent).

Tube	iSTAT-1 Hct (%)	iSTAT-1 Hb (g/dl)	GenS Hct (%)	GenS Hb (g/dl)	Hemocue Hb (g/dl)	Protein (g/dl)	iSTAT – GenS Hct (%)	iSTAT – GenS Hb (g/dl)
1	50	17	48.0	16.9	17.5	6.2	2.0	0.1
2	49	17	47.2	16.8	17.2	4.8	1.8	0.2
3	48	16	47.3	16.9	17.3	3.4	0.7	-0.9
4	47	16	47.4	16.8	17.2	1.9	-0.4	-0.8
5	47	16	45.7	16.9	17.1	1.1	1.3	-0.9
6	33	11	32.4	11.6	12.0	5.2	0.6	-0.6
7	35	12	35.0	12.3	12.8	3.9	0.0	-0.3
8	34	12	35.7	12.7	13.1	2.6	-1.7	-0.7
9	33	11	35.8	12.7	13.1	1.4	-2.8	-1.7
10	33	11	35.7	12.7	13.0	0.7	-2.7	-1.7
11	23	8	22.4	8.0	8.4	5.3	0.6	0.0
12	23	8	23.9	8.5	9.0	4.2	-0.9	-0.5
13	22	7	23.7	8.5	8.8	3.2	-1.7	-1.5
14	21	7	24.3	8.6	9.0	2.1	-3.3	-1.6
15	20	7	24.2	8.6	8.9	1.1	-4.2	-1.6
16	17	6	17.3	6.2	6.6	5.1	-0.3	-0.2
17	19	6	20.1	7.2	7.6	4.0	-1.1	-1.2
18	18	6	19.8	7.2	7.4	3.0	-1.8	-1.2
19	17	6	20.0	7.1	7.4	2.1	-3.0	-1.1
20	16	5	19.9	7.1	7.4	1.1	-3.9	-2.1
21	14	5	14.5	5.3	5.6	4.7	-0.5	-0.3
22	15	5	16.6	6.0	6.3	3.9	-1.6	-1.0
23	15	5	16.6	6.0	6.2	2.9	-1.6	-1.0
24	na	na	na	na	na	na	na	na
25	11	4	15.9	5.7	5.9	0.8	-4.9	-1.7
26	11	4	11.3	4.1	4.4	4.5	-0.3	-0.1
27	10	3	11.9	4.3	4.6	3.6	-1.9	-1.3
28	<10	<	11.7	4.2	4.4	2.6	nc	nc
29	<10	<	11.9	4.3	4.5	1.7	nc	nc
30	<10	<	11.7	4.2	4.4	0.9	nc	nc

nc = not calculated; na = not available (sample was spilled)

Table 4. Comparison of hemoglobin (Hb) and hematocrit (Hct) results obtained with i-STAT-1, Hemocue and GenS instruments.

Method (y)	Method (x)	Diluent solution	Regression equation	S y/x	r	Bias (g/dl)	Limit of agreement (g/dl)			
							Low	High	Delta	N
Hemocue Hb	GenS Hb	Saline	$y = 0.17698 + 1.0171x$	0.1065	0.999	0.34	0.09	0.59	0.50	30
Hemocue Hb	GenS Hb	Ringer's	$y = 0.22366 + 1.0123x$	0.0899	1.000	0.33	0.13	0.54	0.41	29 ¹
iSTAT Hb	GenS Hb	Saline	$y = -1.4783 + 1.0417x$	0.7019	0.975	-1.02	-2.41	0.36	2.77	22 ²
iSTAT Hb	GenS Hb	Ringer's	$y = -1.3546 + 1.0404x$	0.6371	0.978	-0.91	-2.17	0.34	2.51	26 ^{1,3}
iSTAT Hct	GenS Hct	Saline	$y = -3.4028 + 1.0708x$	2.0111	0.979	-1.50	-5.70	2.80	8.50	28 ⁴
iSTAT Hct	GenS Hct	Ringer's	$y = -3.3671 + 1.0785x$	1.5993	0.986	-1.20	-4.80	2.40	7.20	26 ^{1,5}

¹One sample was spilled in the Ringer's group; ² eight i-STAT-1 Hb results were reported as "<"; ³ three i-STAT-1 Hb results were reported as "<"; ⁴ two i-STAT-1 Hct results were reported as "<10"; ⁵ three i-STAT-1 Hct results were reported as "<10."

to 4% for hematocrit were found at the lowest protein concentrations, regardless of which hemodiluent was used. Linear regression analyses for all of the method comparisons gave very high correlation coefficients ($r > 0.900$ [19]). Hemoglobin concentrations obtained with the Hemocue instrument correlated exceedingly well with those obtained with the GenS analyzer (Table 4).

Bland-Altman analysis revealed a constant and relatively negligible positive bias of 0.3 g/dl for hemoglobin results obtained with the Hemocue instrument versus the primary method (Fig. 1 and Table 4). The low level of bias obtained with this optical-based method was unaffected when hemodilution was performed with either the saline or lactated Ringer's solutions. The standard errors of estimate (Sy/x) were relatively low for hemoglobin results obtained with the Hemocue instrument, yielding spans of limit of agreement from low to high values (delta) of 0.50 g/dl for saline and 0.41 g/dl for Ringer's diluted samples. Substantially higher standard errors of estimate (Sy/x) and overall negative bias were observed for H/H results obtained using the iSTAT-1 POCT instrument. Although use of Ringer's solution as the diluent decreased the apparent effect of low protein concentration on the results of the conductivity-based method, the spans of limit of agreement from low to high values (delta) for H/H results obtained with the iSTAT-1 were several fold higher than those with the Hemocue.

Discussion

We found that hemoglobin results obtained using the Hemocue POCT instrument (an optical method) were similar to the hemoglobin results with the GenS hematology analyzer (the primary method). Although a constant bias of 0.3 g/dL for was observed for the Hemocue hemoglobin concentrations, this difference is similar to those reported by other investigators [6,7] and is within the suggested confidence limit of 0.5 g/dl between instruments [8]. Concordance of hemoglobin results between the Hemocue and GenS instruments was expected, since both use optical-based methods for hemoglobin determination. Hemoglobin results with these instruments were unaffected when the reconstituted whole blood samples were diluted with either saline or lactated Ringer's solutions to mimic hemodilution in clinical settings.

Results for H/H obtained with the iSTAT-1 POCT instrument (conductivity methodology) were generally lower than those obtained with the GenS instrument. The degree of discrepancy caused by hypoproteinemia was exacerbated at lower H/H levels, with decreases of up to 2 g/dl for hemoglobin and up to 4% for hematocrit at the lowest protein concentrations tested. The manufacturer of the iSTAT-1 POCT instrument has recognized this problem and recommends that hematocrit results obtained outside of a normal plasma protein range

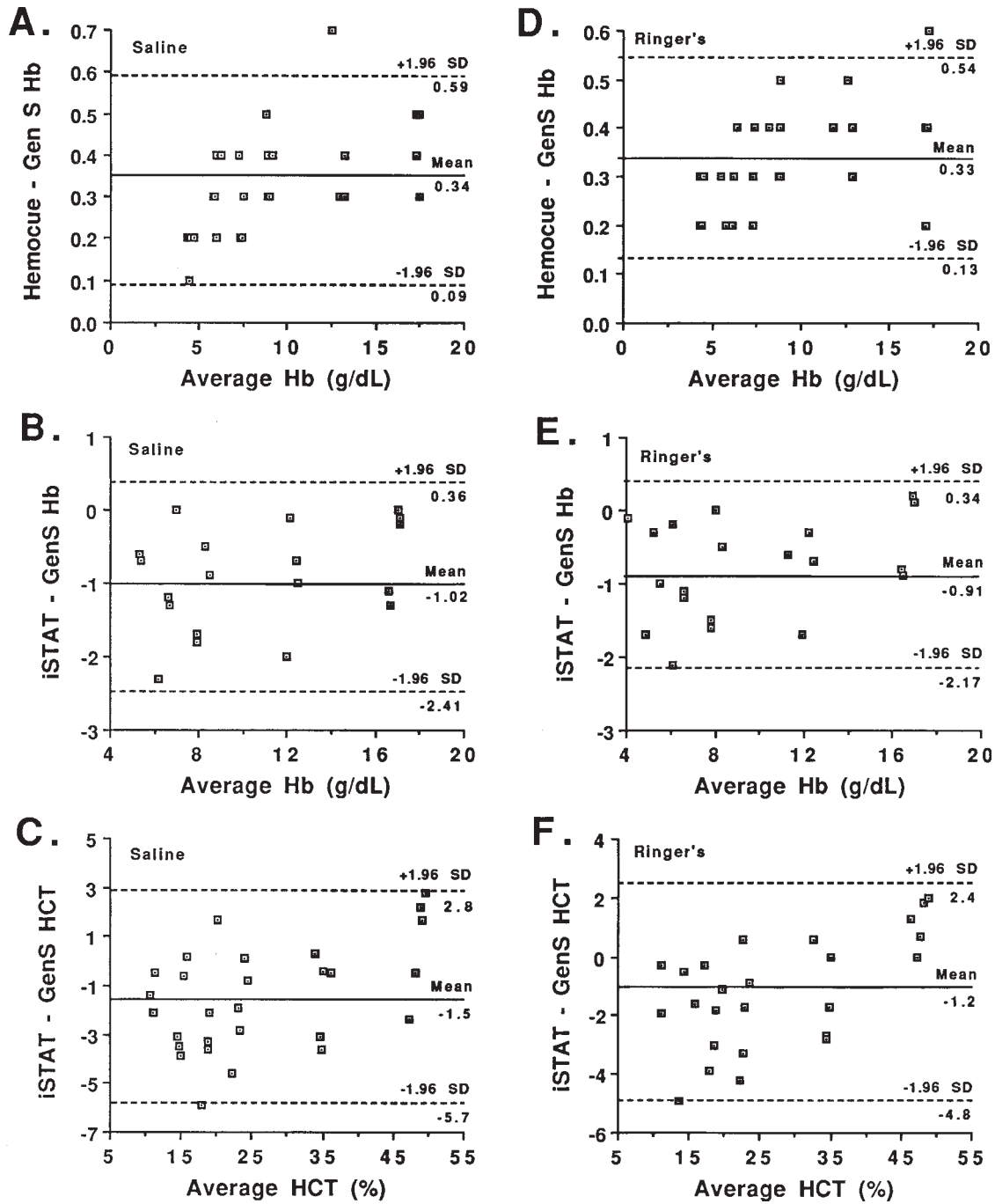


Fig. 1. Bland-Altman plots [18] of saline and Ringer's diluted samples analyzed for hemoglobin and hematocrit using i-STAT-1, Hemocue, and GenS instruments. The means of differences (bias) and limits of agreement (± 1.96 SD) are shown.

of 6.5-8.0 g/dl be adjusted appropriately [14]. In cardiopulmonary bypass (CPB) patients, H/H testing with the iSTAT-1 instrument may be performed in a CPB mode that automatically corrects hematocrit (~3%) for the decreased plasma protein levels typically associated with CPB hemodilution [5]. Alternatively, the manufacturer has suggested that the measured hematocrit be adjusted by 1% for each decrease of 1 g/dl of total plasma protein [14].

Clearly, total plasma protein determination is needed for patients with suspected hypoproteinemia. Since protein determinations are likely to be performed in a main clinical laboratory, this strategy decreases the desirability of POCT. The use of the CPB mode, does, in fact, substantially correct for differences in protein-based conductivity. In a comparison of samples obtained during CPB surgery, use of the CPB mode on the i-STAT instrument increased the correlation coefficient for hemoglobin and hematocrit from 0.46 to 0.95 and from 0.74 to 0.98, respectively [20]. It should be noted that the CPB mode corrects H/H results based on constant positive adjustment of hematocrit. This hematocrit adjustment is incapable of reflecting a variety of protein concentrations. In the absence of CPB, falsely decreased H/H results may still be obtained in critically ill patients with unsuspected hypoproteinemia [11,13,14].

Despite the historical use of a liberal 10/30 (hemoglobin/hematocrit) "transfusion trigger," it has been recommended that more restrictive transfusion guidelines be adopted and that decisions about blood transfusion be based primarily on clinical judgment for patients with hemoglobin concentrations between 7 and 10 g/dl [21-23]. As shown in this study, H/H results may be artifactually decreased by low protein levels when a conductivity-based method is used and this effect is exacerbated at low H/H levels. Knowledge of analytical limitations is fundamental to sound clinical reasoning. This is especially critical for the personnel who perform POCT for critically ill patients [13,14,24,25].

To avoid inappropriate blood transfusions, we recommend that H/H testing in patients with suspected hypoproteinemia or substantial hemodilution should be tested using a non-conductivity-

based technique. At our institution, to avoid possible complications associated with unsuspected hypoproteinemia, the reporting of H/H results has been disabled on iSTAT-1 POCT instruments. Patient samples are analyzed for H/H with the Hemocue instrument or they are sent to the main clinical laboratory for analysis with the GenS instrument.

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References

1. St-Louis P. Status of point-of-care testing: promise, realities, and possibilities. *Clin Biochem* 2000;33:427-440.
2. Bissell M. Point-of-care testing at the millennium. *Crit Care Nurs Q* 2001;24:39-43.
3. Cox CJ. Acute care testing. Blood gases and electrolytes at the point of care. *Clin Lab Med* 2001;21:321-335.
4. McMahan DJ, Carpenter RL. A comparison of conductivity-based hematocrit determinations with conventional laboratory methods in autologous blood transfusions. *Anesth Analg* 1990;71:541-544.
5. Connelly NR, Magee M, Kiessling B. The use of the iSTAT portable analyzer in patients undergoing cardiopulmonary bypass. *J Clin Monit* 1996;12:311-315.
6. Lardi AM, Hirst C, Mortimer AJ, McCollum CN. Evaluation of the HemoCue for measuring intra-operative haemoglobin concentrations: a comparison with the Coulter Max-M. *Anaesthesia* 1998;53:349-352.
7. Rippmann CE, Nett PC, Popovic D, Seifert B, Pasch T, Spahn DR. HemoCue, an accurate bedside method of hemoglobin measurement? *J Clin Monit* 1997;13:373-377.
8. Gehring H, Hornberger C, Dibbelt L, Rothsigkeit A, Gerlach K, Schumacher J, Schmucker P. Accuracy of point-of-care testing (POCT) for determining hemoglobin concentrations. *Acta Anaesthesiol Scand* 2002;46:980-986.
9. Wu J, Petersen JR, Mohammad AA, Okorodudu AO. Point-of-care hemoglobin measurement by Stat-Site MHgb reflectance meter. *Point Care* 2003;2:8-11.
10. McNulty SE, Sharkey SJ, Asam B, Lee JH. Evaluation of STAT-CRIT hematocrit determination in comparison to Coulter and centrifuge: the effects of isotonic hemodilution and albumin administration. *Anesth Analg* 1993;76:830-834.
11. Papadea C, Foster J, Grant S, Ballard SA, Cate JC, Southgate WM, Purohit DM. Evaluation of the iSTAT portable clinical analyzer for point-of-care testing in the

- intensive care units of a university children's hospital. *Ann Clin Lab Sci* 2002;32:231-243.
12. Durward A, Mayer A, Skellett S, Taylor D, Hanna S, Tibby SM, Murdoch IA. Hypoalbuminaemia in critically ill children: incidence, prognosis, and influence on the anion gap. *Arch Dis Child* 2003;88:419-422.
 13. Blunt MC, Nicholson JP, Park GR. Serum albumin and colloid osmotic pressure in survivors and nonsurvivors of prolonged critical illness. *Anaesthesia* 1998;53:755-761.
 14. Implementation Guide and Procedure Manual, i-STAT Corporation, East Windsor, NJ, 1999.
 15. Hemocue, Hemoglobin Photometer Operating Manual, Hemocue AB, Angelholm, Sweden.
 16. Coulter GenS Hematology Analyzer Operating Manual, Beckman-Coulter, Inc., Brea, CA, 1999.
 17. Kingsley GR. The direct biuret method for the determination of serum proteins as applied to photoelectric and visual colorimetry. *J Lab Clin Med* 1942;27:840-845.
 18. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;8:307-310.
 19. Zady MF. Z-stats 12: correlation and simple least squares linear regression (www.westgard.com/lesson42.htm#cc). 2000;1-6.
 20. Schneider J, Dudziak R, Westphal K, Vettermann J. The i-STAT analyzer. A new hand-held device for the bedside determination of hematocrit, blood gases, and electrolytes. *Anaesthesist* 1997;46:701-714.
 21. Carson JL, Willett LR. Is a hemoglobin of 10 g/dL required for surgery? *Med Clin No Amer* 1993;77:335-347.
 22. McFarland JG. Perioperative blood transfusions: indications and options. *Chest* 1999;115(Suppl 5):113S-121S.
 23. Blajchman MA, Herbert PC. Red blood cell transfusion strategies. *Transfus Clin Biol* 2001;8:207-210.
 24. Van Der Linden P. Transfusion strategy. *Eur J Anaesthesiol* 2001;18:495-498.
 25. Jacobs E, Vadasdi E, Sarkozi L, Colman N. Analytical evaluation of i-STAT portable clinical analyzer and use by nonlaboratory health-care professionals. *Clin Chem* 1993;39:1069-1074.