Verification of PO_2 Temperature Correction Factor during Hypothermic Cardiopulmonary Bypass

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Abstract

This study quantitatively investigates two methods of temperature correcting PO_2 values during hypothermic cardiopulmonary bypass. The magnitude of error associated with the linear temperature correction technique increased steadily with decreasing blood temperature, whereas the Kelman-Nunn correction technique closely estimated the reference PO_2 in all cases.

Introduction

Blood Gas Analysis is a standard tool used during heart-lung bypass to evaluate both the performance of the artificial lung and the adequacy of perfusion. Blood gas analysis is usually performed in analyzers with controlled temperature waterbaths set at 37°C since most patients are at normal body temperature. If blood at a temperature other than 37°C is introduced into the blood gas analyzer, the partial pressures of dissolved gases change as temperature equilibration to 37°C occurs. During cardiopulmonary bypass, hypothermia is often induced, so temperature correction of the blood gas data is required.

Several commonly used nomograms for temperature correction are based on the assumption that a linear change in PO_2 is associated with variations in patient temperature.[1,2,3] However, the variation in PO_2 with varying temperature is dependent on the hemoglobin saturation in the range of 83–100%, and the relation becomes linear only when saturation is less than 83%.[4,5,6]

After studying the effects of hemoglobin saturation on the PO_2 temperature correction coefficient, Kelman and Nunn[7] generated the equation $f = .0052 + .0268 (1\text{-}e^{-.3x})$ where x is the percent of reduced hemoglobin at 37°C and f is the temperature coefficient. Once f is derived, the corrected PO_2 is easily obtained by the equation[8] $PO_2 \text{ (at T)} = PO_2 \text{ (at 37°C)} \cdot 10^{f(T-37°C)}$ where T is the patient's blood temperature in degrees Celsius and f is the temperature coefficient. Other investigators[5,9] have mathematically derived f with respect to hemoglobin saturation, and the results are in agreement with Nunn's experimental findings.

The Clinical Chemistry Department at the Medical University of South Carolina has written a computer program using Kelman and Nunn's formula from which a table of correction factors has been generated (Table 1). In this study the PO_2 was calculated with both the Kelman and Nunn and linear temperature correction factors and the results compared.

Methods

Fifty consecutive blood gas samples were taken from an arterial sampling port of the pump-oxygenator circuit during routine cardiopulmonary bypass procedures. Using an in-line PO_2 sensor*, an attempt was made to keep the arterial PO_2 between 100 and 200 Torr. The temperature of the blood varied between 15°C and 36°C as measured by an in-line temperature probe.**

The samples were subjected to the following measurements:

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** Sarns, Inc., Ann Arbor, MI.

Article available at https://ject.edpsciences.org or https://doi.org/10.1051/ject/1980126145

TABLE I

Factors for PO_2 Temperature Correction at a Specific Saturation

Temperature (°C)

Sat.	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
100.0	0.768	0.778	0.787	0.797	0.806	0.816	0.826	0.836	0.846	0.856	0.866	0.877	0.887	0.898	0.909	0.920	0.931	0.942	0.953	0.965	0.976	0.988	1.000	1.012	1.024	1.037
99.5	0.636	0.649	0.663	0.677	0.691	0.705	0.720	0.735	0.750	0.765	0.781	0.798	0.814	0.831	0.848	0.866	0.884	0.902	0.921	0.940	0.960	0.980	1.000	1.021	1.042	1.064
99.0	0.540	0.556	0.572	0.588	0.604	0.622	0.639	0.657	0.676	0.695	0.715	0.735	0.756	0.777	0.800	0.822	0.846	0.869	0.894	0.920	0.946	0.972	1.000	1.028	1.058	1.088
98.5	0.470	0.486	0.503	0.521	0.539	0.558	0.577	0.597	0.618	0.640	0.662	0.685	0.709	0.734	0.760	0.786	0.814	0.842	0.872	0.902	0.934	0.966	1.000	1.035	1.071	1.109
98.0	0.416	0.433	0.451	0.469	0.488	0.508	0.529	0.550	0.573	0.596	0.620	0.645	0.672	0.699	0.727	0.757	0.787	0.819	0.853	0.887	0.923	0.961	1.000	1.041	1.083	1.127
97.5	0.375	0.392	0.410	0.429	0.449	0.469	0.490	0.513	0.536	0.560	0.586	0.613	0.641	0.670	0.700	0.732	0.766	0.800	0.837	0.875	0.915	0.956	1.000	1.046	1.093	1.143
97.0	0.343	0.360	0.378	0.397	0.417	0.438	0.460	0.482	0.506	0.532	0.558	0.586	0.615	0.646	0.678	0.712	0.747	0.784	0.823	0.864	0.907	0.953	1.000	1.050	1.102	1.156
96.5	0.318	0.335	0.353	0.372	0.392	0.412	0.435	0.458	0.482	0.508	0.535	0.564	0.594	0.626	0.659	0.694	0.732	0.771	0.812	0.855	0.901	0.949	1.000	1.053	1.110	1.169
96.0	0.298	0.314	0.332	0.351	0.371	0.392	0.414	0.438	0.462	0.489	0.516	0.545	0.576	0.609	0.644	0.680	0.719	0.759	0.802	0.848	0.896	0.946	1.000	1.057	1.116	1.180
95.5	0.281	0.298	0.315	0.334	0.354	0.375	0.397	0.421	0.446	0.472	0.550	0.530	0.562	0.595	0.630	0.668	0.707	0.749	0.794	0.841	0.891	0.944	1.000	1.059	1.122	1.189
95.0	0.268	0.284	0.302	0.320	0.340	0.361	0.383	0.407	0.432	0.459	0.487	0.517	0.549	0.583	0.619	0.657	0.698	0.741	0.787	0.835	0.887	0.942	1.000	1.062	1.127	1.197
94.5	0.257	0.273	0.290	0.309	0.329	0.350	0.372	0.396	0.421	0.448	0.476	0.507	0.539	0.573	0.610	0.648	0.690	0.734	0.781	0.831	0.884	0.940	1.000	1.064	1.132	1.204
94.0	0.247	0.264	0.281	0.299	0.319	0.340	0.362	0.386	0.411	0.438	0.467	0.497	0.530	0.565	0.602	0.641	0.683	0.728	0.776	0.827	0.881	0.938	1.000	1.066	1.135	1.210
93.5	0.240	0.256	0.273	0.291	0.311	0.332	0.354	0.378	0.403	0.430	0.459	0.490	0.523	0.558	0.595	0.635	0.677	0.723	0.771	0.823	0.878	0.937	1.000	1.067	1.139	1.215
93.0	0.233	0.249	0.266	0.285	0.304	0.325	0.347	0.371	0.396	0.423	0.452	0.483	0.516	0.551	0.589	0.629	0.672	0.718	0.768	0.820	0.876	0.936	1.000	1.068	1.141	1.219
92.5	0.228	0.244	0.261	0.279	0.298	0.319	0.341	0.365	0.390	0.418	0.447	0.478	0.511	0.546	0.584	0.625	0.668	0.715	0.764	0.817	0.874	0.935	1.000	1.069	1.144	1.223
92.0	0.224	0.239	0.256	0.274	0.294	0.314	0.336	0.360	0.386	0.413	0.442	0.473	0.506	0.542	0.580	0.621	0.665	0.711	0.762	0.815	0.873	0.934	1.000	1.070	1.146	1.227
91.5	0.220	0.235	0.252	0.270	0.290	0.310	0.332	0.356	0.381	0.409	0.438	0.469	0.502	0.538	0.576	0.618	0.662	0.709	0.759	0.813	0.871	0.933	1.000	1.071	1.148	1.229
91.0	0.217	0.232	0.249	0.267	0.286	0.307	0.329	0.352	0.378	0.405	0.434	0.465	0.499	0.535	0.573	0.615	0.659	0.706	0.757	0.812	0.870	0.933	1.000	1.072	1.149	1.232
90.5	0.214	0.229	0.246	0.264	0.283	0.304	0.326	0.349	0.375	0.402	0.431	0.462	0.496	0.532	0.571	0.612	0.657	0.704	0.755	0.810	0.869	0.932	1.000	1.073	1.151	1.234
90.0	0.212	0.227	0.244	0.261	0.281	0.301	0.323	0.347	0.372	0.399	0.429	0.460	0.494	0.530	0.568	0.610	0.655	0.703	0.754	0.809	0.868	0.932	1.000	1.073	1.152	1.236
89.5	0.210	0.225	0.242	0.259	0.278	0.299	0.321	0.345	0.370	0.397	0.426	0.458	0.492	0.528	0.566	0.608	0.653	0.701	0.753	0.808	0.868	0.931	1.000	1.074	1.153	1.238
89.0	0.208	0.223	0.240	0.257	0.277	0.297	0.319	0.343	0.368	0.395	0.424	0.456	0.490	0.526	0.565	0.607	0.652	0.700	0.752	0.807	0.867	0.931	1.000	1.074	1.154	1.239
88.5	0.206	0.222	0.238	0.256	0.275	0.295	0.317	0.341	0.366	0.394	0.423	0.454	0.488	0.524	0.563	0.605	0.650	0.699	0.751	0.806	0.866	0.931	1.000	1.074	1.154	1.240
88.0	0.205	0.220	0.237	0.255	0.274	0.294	0.316	0.340	0.365	0.392	0.421	0.453	0.487	0.523	0.562	0.604	0.649	0.698	0.750	0.806	0.866	0.931	1.000	1.075	1.155	1.241
87.5	0.204	0.219	0.236	0.253	0.272	0.293	0.315	0.338	0.364	0.391	0.420	0.452	0.486	0.522	0.561	0.603	0.648	0.697	0.749	0.805	0.865	0.930	1.000	1.075	1.155	1.242
87.0	0.203	0.218	0.235	0.253	0.271	0.292	0.314	0.337	0.363	0.390	0.419	0.451	0.485	0.521	0.560	0.602	0.648	0.696	0.748	0.805	0.865	0.930	1.000	1.075	1.156	1.242
86.5	0.202	0.218	0.234	0.252	0.271	0.291	0.313	0.337	0.362	0.389	0.418	0.450	0.484	0.520	0.559	0.602	0.647	0.696	0.748	0.804	0.865	0.930	1.000	1.075	1.156	1.243
86.0	0.202	0.217	0.233	0.251	0.270	0.290	0.312	0.336	0.361	0.388	0.418	0.449	0.483	0.520	0.559	0.601	0.646	0.695	0.747	0.804	0.865	0.930	1.000	1.075	1.157	1.244
85.5	0.201	0.216	0.233	0.250	0.269	0.290	0.312	0.335	0.360	0.388	0.417	0.449	0.482	0.519	0.558	0.600	0.646	0.695	0.747	0.804	0.864	0.930	1.000	1.076	1.157	1.244
85.0	0.201	0.216	0.232	0.250	0.269	0.289	0.311	0.335	0.360	0.387	0.416	0.448	0.482	0.518	0.558	0.600	0.645	0.694	0.747	0.803	0.864	0.930	1.000	1.076	1.157	1.245
84.5	0.200	0.215	0.232	0.249	0.268	0.289	0.311	0.334	0.359	0.387	0.416	0.448	0.481	0.518	0.557	0.600	0.645	0.694	0.746	0.803	0.864	0.930	1.000	1.076	1.157	1.245
84.0	0.200	0.215	0.231	0.249	0.268	0.288	0.310	0.334	0.359	0.386	0.416	0.447	0.481	0.518	0.557	0.599	0.645	0.694	0.746	0.803	0.864	0.929	1.000	1.076	1.158	1.245
83.5	0.200	0.215	0.231	0.249	0.268	0.288	0.310	0.333	0.359	0.386	0.415	0.447	0.481	0.517	0.557	0.599	0.644	0.693	0.746	0.803	0.864	0.929	1.000	1.076	1.158	1.246
83.0	0.199	0.215	0.231	0.248	0.267	0.288	0.309	0.333	0.358	0.386	0.415	0.446	0.480	0.517	0.556	0.599	0.644	0.693	0.746	0.803	0.864	0.929	1.000	1.076	1.158	1.246

Directions:
1) The PO_2 factor can be found on the line opposite the O_2 saturation under the patient's temperature.
2) Multiply PO_2 as analyzed at 37° by PO_2 factor and calculate the corrected PO_2 at the patient's temperature.
3) For all O_2 saturations less than 83%, use the appropriate factor at 83.

TABLE II

Comparison of Reference PO_2 to Corrected PO_2's Calculated Using Linear and Kelman-Nunn Techniques

TEMP. (°C)	NO. OF SAMPLES	REFERENCE PO_2 (mmHg)	UNCORRECTED PO_2 (IL513) mmHg	% sat.	CORRECTED LINEAR PO_2 mmHg	% deviation from reference	CORRECTED KELMAN-NUNN PO_2 mmHg	% deviation from reference
36	1	128.0	130.0	99.7	121.1	5.5 ± 0.0	128.0	0.0 ± 0
35	4	144.3	152.7	99.6	131.3	4.7 ± 2.3	147.3	4.3 ± 0.8
34	2	147.5	165.5	99.3	131.5	10.1 ± 3.9	155.0	6.9 ± 2.9
33	1	110.0	118.0	99.1	88.4	16.0 ± 0.0	106.0	3.6 ± 0.0
32	5	149.0	179.5	99.8	125.6	12.3 ± 4.7	166.0	15.4 ± 3.2
31	2	117.5	134.5	99.3	87.5	23.0 ± 5.0	117.5	9.4 ± 0.6
30	2	127.5	141.8	99.3	89.0	29.5 ± 5.0	119.5	5.5 ± 5.5
29	4	140.8	158.4	99.5	88.7	35.5 ± 2.8	135.7	5.3 ± 0.7
28	6	124.0	130.1	99.5	76.3	35.7 ± 0.9	123.8	2.2 ± 0.8
27	6	134.7	156.3	99.6	75.0	43.2 ± 1.3	130.0	7.0 ± 2.3
25	4	163.7	205.0	99.7	86.1	45.6 ± 2.7	169.7	9.0 ± 2.1
24	1	170.0	183.0	99.4	71.4	57.0 ± 0.0	137.0	19.4 ± 0.0
23	1	265.0	281.0	100.0	101.2	60.0 ± 0.0	237.0	10.6 ± 0.0
22	4	162.5	215.5	99.7	73.3	52.5 ± 3.5	169.7	9.4 ± 5.7
20	2	207.5	322.0	100.0	93.4	53.5 ± 1.5	261.0	24.9 ± 3.6
18	4	152.5	237.5	99.5	62.0	58.3 ± 3.6	158.7	13.7 ± 5.7
15	1	190.0	274.0	100.0	57.5	70.0 ± 0.0	207.0	8.9 ± 0.0

1. Analysis by an Instrumentation Laboratories 513 analyzer at 37°C. These raw data were temperature corrected by the Kelman-Nunn and linear (7% per °C) methods.

2. Analysis by an Instrumentation Laboratories 213 Analyzer operating at the blood temperature of the patient.

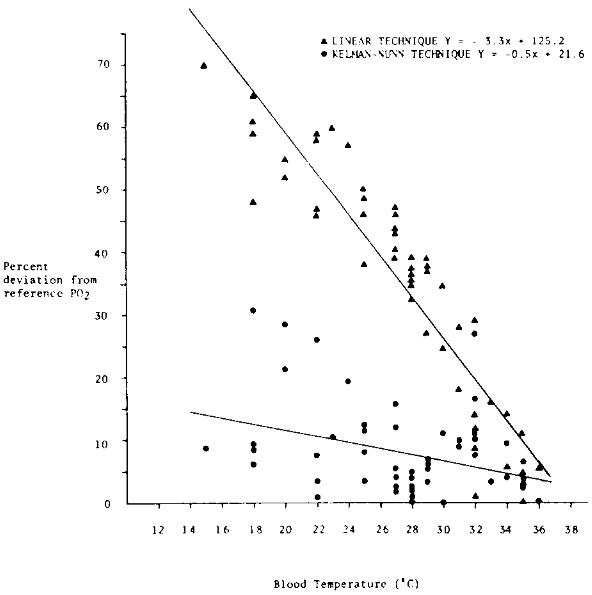

FIGURE 1. Percent deviation associated with corrected PO_2 data at varying blood temperatures.

All of the preceding data were compared to concurrent PO_2 readings from an in-line PO_2 electrode placed next to the sampling site and adjacent to the temperature probe. The data collected were analyzed with the use of the student t test as well as regression and correlation analysis. Standard error of the mean was calculated for percent deviations from the reference PO_2 for both techniques at varying blood temperatures.

Results

Table 2 summarizes the data for the 50 consecutive blood gases analyzed in this study. The reference PO_2 was the average of the IL 213 and the Critikon PO_2. The reference PO_2 may be considered the true PO_2 since correlation between the two was excellent ($r = .99$, $p < .001$).

In addition to the reference PO_2, Table 2 contains the corrected PO_2 values by both methods. A very high correlation existed between the reference PO_2 and PO_2 derived by the Kelman and Nunn technique ($r = .90$, $p < .001$). On the other hand, correlation of the reference PO_2 with PO_2 derived using the linear correction factor was poor ($r = .06$, $p > .50$).

Differences between derived PO_2 and reference PO_2 were expressed as percent deviation (Figure 1). The Kelman-Nunn PO_2 deviated from the reference PO_2 by an average of 9.2 ± 6.3%, whereas the linearly corrected PO_2 deviated by 37.9 ± 20.8% ($p < .001$). Figure 1 vividly demonstrates an increasingly large error in the linear method of correction as patient temperature diverges from 37°C.

Discussion

The use of the linear temperature correction technique to calculate PO_2 during hypothermic cardiopulmonary bypass produces spurious results. The dependence of PO_2 temperature correction on oxygen saturation cannot be ignored. The degree of error of linear temperature correction increases linearly with decreasing temperature, as Figure 1 dramatically illustrates. On the other hand, the Kelman-Nunn correction closely estimated the reference PO_2 in all cases, and we recommend its routine use during hypothermic cardiopulmonary bypass. The difficulties of temperature correction can be obviated by the use of a properly calibrated in-line PO_2 analyzer, which displays PO_2 continuously and is both convenient and accurate.

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