31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Anesthetic Gas Concentration Changes Related to the Temperature and Humidity in High and Low Flow Anesthesia

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Abstract— **The objective of this study, is to investigate the effects of the temperature and the humidity to the amount of anesthetic gas output from the vaporizer in both high and low flow anesthesia, and to attract attention to this relationship during the delivery of anesthesia and the calibration measurements.**

The performance of the anesthesia vaporizer (isoflurane and sevoflurane) was evaluated in both high and low flow anesthesia, and it was investigated whether the vaporizer supplied the preset amount of anesthetic to the patient. Then, through changing the temperature of the anesthetic device between 20 and 36°C, and through changing the humidity between 20% and 42%, the changes in the gas concentration were measured.

After measurements, the results were studied statically. For high and low flow anesthesia, the regression equations were obtained and it was seen that these equations were acceptable.

I. Introduction

During the anesthesia applications, dose misadjustments are one of the mistakes and should be taken into consideration [1]. Thus, controlling and measuring the concentration of anesthetic agent yield safer anesthesia application [2][3]. In health studies, especially in anesthesia application, calibration is important. Calibration is a process of measuring and documenting the accuracy of test and measuring devices and determining the deviation of these devices by using a measurement standard or system that is known to be accurate. Because of this, the parameters affecting the accuracy that are temperature and humidity in anesthesia,, are important.

In anesthesia, because the maximum output of the vaporizer depends on the vapor pressure of the anesthetic agent, and the vapor pressure also depends on the temperature, the preset concentration in the vaporizer is not equal to the actual gas concentration given to the patient.

In this study, the effects of temperature and the humidity changes to the anesthetic gas concentration were studied for both high and low flow anesthesia by using an anesthesia vaporizer that does not compensate the temperature.

Manuscript received April 7, 2009.

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High flow anesthesia uses a fresh gas flow, which is close to the patient's minute ventilation (on average 3 to 6 L/min in a normal adult). Also, low flow anesthesia uses a fresh gas flow of less than half the minute ventilation of the patient, which is less than 3.0 L/min on average in a normal adult.

II. Method

In our study, the anesthetic agent concentrations were measured within the breath system. While for the measurement of the anesthetic agent concentration, a Multi Gas Analyzer that automatically separates the anesthetic gases was used. Agilent 34907A was employed for the temperature measurements.

In the high flow anesthesia, the flow was adjusted to 5L/min. The gas concentrations, in normal conditions, were measured by adjusting concentration scale in small steps. Hence, the information about the performance of the vaporizer in normal conditions was obtained. After this, the temperature was changed from 20°C to 36°C with the increments of 2°C and the humidity was changed from 20% to 42% with the increments of 2%, concentration measurements were repeated. This temperature and humidity range are used because of the potansiometer range of the used humidifier.

To investigate the effects of the temperature and the humidity to the gas concentration in the low flow anesthesia, the flow was adjusted to 1L/min. and all measurement procedures mentioned above were repeated.

The obtained measurement results were analyzed by using a multiple regression to investigate the functional structure between the dependent variables and the independent variables. Thus, the different regression equations were determined for high flow and low flow anesthesia separately.

III. Results

A. Temperature Parameters

In both high and low flow, the gas concentration (sevoflurane and isoflurane) were measured through changing the temperature of device between 20 and 36°C with the increments of 2 °C. In the results, % values mean the anesthetic gas concentration.

1) High Flow (Sevoflurane): The measured sevoflurane concentrations for different temperatures in high flow, are given in Table I. The mean and the standard deviation of these results are shown in Table II.

TABLE I
SEVOFLURANE CHANGES WITH TEMPERATURE IN HIGH FLOW

Sevo. (%)	1%	2%	4%	6%	8%
20^0C	0.90	1.91	3.92	5.91	7.92
22^0C	0.94	1.96	3.98	5.98	7.98
24^0C	0.96	2.00	4.00	6.00	8.00
25^0C	1.00	2.00	4.00	6.00	8.00
26^0C	1.03	2.00	4.02	6.04	8.02
28^0C	1.13	2.09	4.10	6.12	8.09
30^0C	1.23	2.20	4.23	6.20	8.21
32^0C	1.23	2.21	4.26	6.22	8.22
34^0C	1.24	2.23	4.26	6.24	8.24
36^0C	1.24	2.23	4.27	6.25	8.24

TABLE II
MEAN AND STD. OF SEVOFLURANE CONCENTRATIONS WITH DIFFERENT TEMPERATURE (HIGH FLOW)

Sevoflurane (%)	1%	2%	4%	6%	8%
Mean	1.09	2.08	4.10	6.10	8.09
Standard deviation	0.1386	0.1241	0.1374	0.1251	0.1239

From the measurement results, the regression equation is obtained as in (1). Here, A_s is the adjusted, M_s is the measured sevoflurane concentration, and T is the temperature.

$$M_s = -0.56764 + 1.000945 * A_s + 0.023792 * T \quad (1)$$

It is seen that coefficients of the regression equation is statistically significant (p=1.37E-88<0.05).

2) *High Flow (Isoflurane):* The measured isoflurane concentrations for different temperatures in high flow, are given in Table III. The mean and the standard deviation of these results are shown in Table IV.

TABLE III
ISOFLURANE CHANGES WITH TEMPERATURE IN HIGH FLOW

Iso. (%)	1%	2%	3%	4%	5%
20^0C	0.92	1.92	2.91	3.91	4.93
22^0C	0.94	1.96	2.98	3.99	4.98
24^0C	0.96	2.00	3.00	4.00	5.00
25^0C	0.98	2.00	3.00	4.00	5.01
26^0C	1.02	2.02	3.00	4.01	5.01
28^0C	1.08	2.09	3.10	4.11	5.10
30^0C	1.16	2.18	3.20	4.20	5.21
32^0C	1.18	2.19	3.20	4.21	5.22
34^0C	1.18	2.19	3.22	4.22	5.22
36^0C	1.18	2.19	3.22	4.22	5.23

TABLE IV
MEAN AND STD. OF ISOFLURANE CONCENTRATIONS WITH DIFFERENT TEMPERATURE (HIGH FLOW)

Isoflurane (%)	1%	2%	3%	4%	5%
Mean	1.06	2.07	3.08	4.09	5.09
Standard deviation	0.1083	0.1066	0.1185	0.1181	0.1186

$$M_i = -0.51572 + 1.0075 * A_i + 0.020733 * T \quad (2)$$

is calculated as the regression equation (2) and it is assigned that this regression equation is acceptable (p=6.91E-78<0.05). Here, A_i is the adjusted, M_i is the measured isoflurane concentration, and T is the temperature.

3) *Low Flow (Sevoflurane):* The measured sevoflurane concentrations for different temperatures in low flow, are given in Table V. The mean and the standard deviation of these results are shown in Table VI.

TABLE V
SEVOFLURANE CHANGES WITH TEMPERATURE IN LOW FLOW

Sevo. (%)	1%	2%	4%	6%	8%
20^0C	0.90	1.91	3.92	5.92	7.93
22^0C	0.96	1.97	3.98	5.98	7.98
24^0C	0.99	2.00	4.00	6.00	8.00
25^0C	1.00	2.00	4.00	6.00	8.02
26^0C	1.03	2.03	4.00	6.00	8.03
28^0C	1.10	2.10	4.09	6.07	8.07
30^0C	1.19	2.20	4.22	6.19	8.21
32^0C	1.21	2.21	4.23	6.23	8.23
34^0C	1.21	2.22	4.24	6.25	8.23
36^0C	1.22	2.22	4.24	6.25	8.24

TABLE VI
MEAN AND STD. OF SEVOFLURANE CONCENTRATIONS WITH DIFFERENT TEMPERATURE (LOW FLOW)

Sevoflurane (%)	1%	2%	4%	6%	8%
Mean	1.08	2.09	4.09	6.09	8.09
Standard deviation	0.1200	0.1187	0.1277	0.1276	0.1205

From the measurement results, the regression equation is obtained as in (3). Here, A_s is the adjusted, M_s is the measured sevoflurane concentration, and T is the temperature.

$$M_s = -0.543 + 1.001543 * A_s + 0.02256 * T \quad (3)$$

It is seen that coefficients of the regression equation is statistically significant (p=1.29E-90<0.05).

4) *Low Flow (Isoflurane):* The measured isoflurane concentrations for different temperatures in low flow, are

given in Table VII. The mean and the standard deviation of these results are shown in Table VIII.

TABLE VII
ISOFLURANE CHANGES WITH TEMPERATURE IN LOW FLOW

Iso. (%)	1%	2%	3%	4%	5%
20^0C	0.93	1.94	2.94	3.95	4.94
22^0C	0.94	1.96	2.98	3.98	4.98
24^0C	0.96	2.00	3.00	4.00	5.00
25^0C	0.98	2.00	3.00	4.01	5.02
26^0C	1.02	2.02	3.01	4.03	5.05
28^0C	1.09	2.09	3.06	4.10	5.10
30^0C	1.18	2.17	3.19	4.18	5.18
32^0C	1.19	2.20	3.21	4.19	5.18
34^0C	1.19	2.20	3.23	4.19	5.19
36^0C	1.19	2.21	3.23	4.23	5.24

TABLE VIII
MEAN AND STD. OF ISOFLURANE CONCENTRATIONS WITH DIFFERENT TEMPERATURE (LOW FLOW)

Isoflurane (%)	1%	2%	3%	4%	5%
Mean	1.067	2.079	3.085	4.086	5.088
Standard deviation	0.113	0.108	0.116	0.104	0.104

$$M_i = -0.48681 + 1.0049 * A_i + 0.02004 * T \quad (4)$$

is calculated as the regression equation (4) and it is assigned that this regression equation is acceptable (p=2.38E-81<0.05). Here, A_i is the adjusted, M_i is the measured isoflurane concentration, and T is the temperature.

B. Humidity Parameters

In both high and low flow, the gas concentration (sevoflurane and isoflurane) were measured through changing the humidity between 20% and 42% with the increments of 2%. In the results, % values mean the anesthetic gas concentration.

1) *High Flow (Sevoflurane):* The measured sevoflurane concentrations for different humidities in high flow, are given in Table IX. The mean and the standard deviation of these results are shown in Table X.

From the measurement results, the regression equation is obtained as in (5). Here, A_s is the adjusted, M_s is the measured sevoflurane concentration, and H is the humidity.

$$M_s = -0.08421 + 1.000116 * A_s + 0.002578 * H \quad (5)$$

It is seen that coefficients of the regression equation is statistically significant (p=2.1E-110<0.05).

TABLE IX
SEVOFLURANE CHANGES WITH HUMIDITY IN HIGH FLOW

Sevo. (%)	1%	2%	4%	6%	8%
20%	0.97	1.95	3.95	5.96	7.97
22%	0.97	1.96	3.96	5.96	7.97
26%	0.99	1.98	3.99	5.99	7.99
28%	1.00	2.00	4.00	6.00	8.00
30%	1.00	2.00	4.00	6.00	8.00
32%	1.00	2.00	4.00	6.00	8.00
34%	1.00	2.01	4.00	6.01	8.01
36%	1.01	2.02	4.01	6.01	8.01
40%	1.02	2.02	4.01	6.01	8.02
42%	1.02	2.02	4.01	6.01	8.02

TABLE X
MEAN AND STD. OF SEVOFLURANE CONCENTRATIONS WITH DIFFERENT HUMIDITY (HIGH FLOW)

Sevoflurane (%)	1%	2%	4%	6%	8%
Mean	1.00	2.00	3.99	6.00	8.00
Standard deviation	0.017	0.0250	0.0211	0.0196	0.0179

2) *High Flow (Isoflurane):* The measured isoflurane concentrations for different humidities in high flow, are given in Table XI. The mean and the standard deviation of these results are shown in Table XII.

TABLE XI
ISOFLURANE CHANGES WITH HUMIDITY IN HIGH FLOW

Iso. (%)	1%	2%	3%	4%	5%
20%	0.90	1.93	2.95	3.96	4.97
22%	0.91	1.95	2.96	3.96	4.97
26%	0.95	1.98	2.99	3.99	4.99
28%	0.96	2.00	3.00	4.00	5.00
30%	0.98	2.00	3.00	4.00	5.00
32%	1.00	2.00	3.00	4.00	5.00
34%	1.00	2.01	3.00	4.01	5.01
36%	1.01	2.01	3.01	4.01	5.01
40%	1.02	2.02	3.02	4.03	5.03
42%	1.02	2.02	3.02	4.03	5.03

TABLE XII
MEAN AND STD. OF ISOFLURANE CONCENTRATIONS WITH DIFFERENT HUMIDITY (HIGH FLOW)

Isoflurane (%)	**1%**	**2%**	**3%**	**4%**	**5%**
Mean	0.98	1.99	3.00	4.00	5.00
Standard deviation	0.0438	0.0301	0.0232	0.0242	0.0208

$$M_i = -0.14067 + 1.0059 * A_i + 0.003722 * H \quad (6)$$

is calculated as the regression equation (6) and it is assigned that this regression equation is acceptable ($p=6.5E-98<0.05$). Here, A_i is the adjusted, M_i is the measured isoflurane concentration, and H is the humidity.

3) *Low Flow (Sevoflurane):* The measured sevoflurane concentrations for different humidities in low flow, are given in Table XIII. The mean and the standard deviation of these results are shown in Table XIV.

TABLE XIII
SEVOFLURANE CHANGES WITH HUMIDITY IN LOW FLOW

Sevo. (%)	1%	2%	4%	6%	8%
20%	0.94	1.93	3.95	5.96	7.97
22%	0.95	1.95	3.96	5.96	7.97
26%	0.96	1.98	3.99	5.99	7.99
28%	0.98	2.00	4.00	6.00	8.00
30%	0.98	2.00	4.00	6.00	8.00
32%	1.00	2.00	4.00	6.00	8.00
34%	1.00	2.01	4.00	6.01	8.01
36%	1.01	2.01	4.00	6.01	8.02
40%	1.01	2.01	4.01	6.02	8.02
42%	1.01	2.02	4.01	6.02	8.03

TABLE XIV
MEAN AND STD. OF SEVOFLURANE CONCENTRATIONS WITH DIFFERENT HUMIDITY (LOW FLOW)

Sevoflurane (%)	**1%**	**2%**	**4%**	**6%**	**8%**
Mean	0.98	1.99	3.99	6.00	8.00
Standard deviation	0.0263	0.0292	0.0204	0.0216	0.0202

$$M_s = -0.10935 + 1.002165 * A_s + 0.003008 * H \quad (7)$$

is calculated as the regression equation (7) and it is assigned that this regression equation is acceptable ($p=1.3E-115<0.05$). Here, A_s is the adjusted, M_s is the measured isoflurane concentration, and H is the humidity.

4) *Low Flow (Isoflurane):* The measured isoflurane concentrations for different humidities in low flow, are given in Table XV. The mean and the standard deviation of these results are shown in Table XVI.

From the measurement results, the regression equation is obtained as in (8). Here, A_i is the adjusted, M_i is the measured isoflurane concentration, and H is the humidity.

$$M_i = -0.14562 + 1.0042 * A_i + 0.003962 * H \quad (8)$$

It is seen that coefficients of the regression equation is statistically significant ($p=1.59E-95<0.05$).

TABLE XV
ISOFLURANE CHANGES WITH HUMIDITY IN LOW FLOW

Iso. (%)	1%	2%	3%	4%	5%
20%	0.90	1.93	2.94	3.94	4.93
22%	0.91	1.95	2.96	3.96	4.95
26%	0.95	1.98	2.99	3.99	4.99
28%	0.96	2.00	3.00	4.00	5.00
30%	0.98	2.00	3.00	4.00	5.00
32%	1.00	2.00	3.00	4.00	5.00
34%	1.00	2.01	3.00	4.01	5.01
36%	1.01	2.01	3.01	4.01	5.01
40%	1.02	2.01	3.02	4.02	5.02
42%	1.02	2.02	3.02	4.02	5.03

TABLE XVI
MEAN AND STD. OF ISOFLURANE CONCENTRATIONS WITH DIFFERENT HUMIDITY (LOW FLOW)

Isoflurane (%)	1%	2%	3%	4%	5%
Mean	0.98	1.99	2.99	4.00	4.99
Standard deviation	0.0438	0.0292	0.0255	0.0259	0.0310

IV. CONCLUSION

In this study, the effect of the temperature and the humidity to the anesthetic gas concentration was studied and it was seen that the anesthetic gas concentration had little difference related to the temperature and the humidity for both high and low flow anesthesia. Although the effect is minimal, the gas concentration should be defined by using different prediction equations (regression equations) because of the different application of the high and low flow anesthesia. Additionally, the operator of anesthesia also should take care of this difference for correct adjustment.

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