Original Article

Measurement of consumption of sevoflurane for short pediatric anesthetic procedures: Comparison between Dion's method and Dragger algorithm

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Abstract

Background: The most common drugs used in an operating room are the "Inhalation agents" for maintenance of anesthesia yet their measurement methods during the procedure are not well-validated. Conventional methods of measuring the vaporizer weight after each use suffers from practical limitations of high error and time constraints.
Aims: We compared two alternative methods available (Dion's method and Drager Inc. patent protocol) for their degree of concordance and correlation in real-time consumption of sevoflurane for pediatric procedures.
Methodology: One hundred pediatric patients scheduled for ophthalmological examination under anesthesia were included in the study. Anesthesia was induced and maintained using sevoflurane with oxygen and nitrous oxide (1:1) on Primus workstation (Drager Inc., Germany). Total sevoflurane consumed for each procedure was calculated using Dion's equation and the values obtained from Drager Primus were noted and compared.
Results: Both methods showed a very strong correlation (0.895 [$P < 0.001$]). Dion's method underestimated consumption by 2.59 ml with limits of agreement between 5.188 ml and −0.008 ml. Both test results showed a strong correlation, but poor concordance.
Conclusions: Dion's method strongly correlates with Drager protocol although concordance between the two methods for measuring anesthetic gas consumption is poor. Dion's method underestimates the consumption and with slight modification addressing this underestimation, it can be electronically incorporated in other workstations to overcome limitations of real-time measurement of inhalation agent consumption.

Key words: Dion's equation, Drager workstation, measuring inhalation agent consumption, sevoflurane consumption

Introduction

Inhalation agents are the most frequently used drugs in the operating room. During administration of balanced anesthesia, it is very difficult to estimate the correct quantity of these agents used and thus calculate the cost incurred because of their usage.[1] The basic problem is the lack of easily usable practical methods of estimation of their usage. Sevoflurane is a widely accepted volatile anesthetic agent, which is supplied as liquid and each milliliter of supplied liquid generates around 180 ml of vapor.[2] Thus, the supply as "liquid" and consumption as "gas," further adds to limitations of measuring its consumed amount. Furthermore, the classical method of weighing the vaporizer before and after use, can give the amount of consumed liquid,[3] but any small error in measuring liquid's weight would be multiplied around 180 times for vapor volume generated. In a busy operating room, removing vaporizer and measuring its weight after each case may not be feasible as well.

A routinely usable method not requiring any special technology for estimation of consumed inhalation agent was proposed by Dion.[4] The method has been used in many studies for measuring the amount of inhalation agent consumed; however, the results have not been validated against any other method. Dion's method uses an equation measuring the percentage of agents on dial setting and duration for which it remains. It assumes anesthetic vapors to behave as ideal gases and

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thus their molar consumptions are calculated from volume of gaseous agent consumed. Another method that gives estimation by actually measuring volume of anesthetic vapors in the circuit is available in anesthesia machines marketed by Drager Inc., Germany. This method uses an algorithm measuring gas consumption on the basis of agent concentration in the circuit measured via the sampling line on a continuous basis.

We evaluated the accuracy of Dion's method comparing it to the method used in Drager Primus anesthesia workstations. This is the first study validating use of Dion's method against a method of physically measuring consumed anesthesia vapor.

Materials and Methods

After an institutional ethical review board approval the study was initiated in ophthalmological operating unit of a tertiary care center. One hundred (American Society of Anesthesiologists – Grade I and II) pediatric patients scheduled for ophthalmological examination under anesthesia (EUA), between age of 1 year and 8 years were included in the study after informed written parental consent. Patients with suspected difficult airway, seizure disorder and difficult intravenous cannulation were excluded from the study. All patients were pre-medicated in parental presence in the pre-anesthesia room using oral midazolam (0.5 mg/kg) ½ h prior to the procedure. For anesthesia induction and maintenance – A Drager anesthesia workstation (Primus) was used for all 100 patients.

In the operating room, after connecting standard monitoring, anesthesia was induced using incremental concentrations of sevoflurane starting from 1% and increasing by 1% every 4th breath until 8% dial concentration was reached. As per standard induction protocols, a fresh gas flow of 6 L/min with oxygen and nitrous oxide (1:1 ratio) via the closed circuit was used during the same. An observer using a stopwatch noted the time period for each dial concentration in seconds. Once anesthesia was induced (defined by loss of eyelash reflex and central eye position) the sevoflurane dial concentration setting was reduced to 4%. An intravenous line was inserted following which an optimal size classical laryngeal mask airway (LMA) was placed and cumulative time duration for the same was noted. After confirming satisfactory positioning of the LMA, the fresh gas flow was reduced to 2 L/min (oxygen:Nitrous oxide = 1:1), during the maintenance phase sevoflurane concentration was titrated to a predetermined clinical end point (central eye position allowing the EUA and the child was allowed to breath spontaneously during the procedure. An observer continued to note the time period and corresponding dial concentration during the maintenance phase as well. Once the surgeon confirmed completion of procedure, sevoflurane and nitrous oxide were switched off increasing the fresh gas flow of oxygen to 6 L. Upon removal of LMA in each patient, volume of sevoflurane consumed for the procedure was noted from the Drager Primus case summary menu. The volume of sevoflurane consumed for the procedure was also calculated using the Dion's method as follows.

Calculations

Total sevoflurane consumed = consumption during induction + consumption during maintenance

Amount of liquid sevoflurane used = PFTM/2412d

Where the variables represent

- P Vaporizer dial concentration in percent
- F Total fresh gas flow in liters/minute
- T Time for which the concentration P was set in minutes
- M Molecular mass of sevoflurane in grams
- d Density of liquid sevoflurane in grams/milliliter

The fixed variables used were

- F (total fresh gas flow) set at 6 L/min (induction), 2 L/min (maintenance)
- M (molecular mass of sevoflurane) = 200.055 mg
- d (density of sevoflurane at 21°C) = 1.52 g/ml

Substituting the fixed variables the equation can be re-written as:

Amount of liquid sevoflurane used = 0.00546 PT (where T is in seconds)

The time period for each concentration was labeled as T_1, T_2, T_3 so on until T_8 in seconds for concentration of 1%, 2%, 3% till 8%

Total liquid sevoflurane used was calculated as:

$$0.00546\,(T_1 + 2T_2 + 3T_3 + 4T_4 + 5T_5 + 6T_6 + 7T_7 + 8T_8 + 4tIV + 4tLMA)$$

Where, tIV and tLMA are times for intravenous cannulation and successful LMA placement.

Similarly for maintenance with the flow at 2 L/min

$$0.00182\,(\%1T_1 + \%2T_2 + \ldots\ldots)$$

Where % and T represents dial setting and time for that setting respectively.

Statistical analysis

The data obtained was analyzed using the SPSS 16 (IBM Inc.) for Macintosh. Parametric data of all patients was summed up using the descriptive statistics. Non-parametric variable (values from Dion's method and Drager protocol) were compared using Bland and Altman method and level of agreement was calculated. The relation among these methods was estimated using Spearman's correlation coefficient. As no previous research on the topic was available, thus "effect size" variable to calculate sample size did not exist; therefore, a sample size prior to study could not be validated for the present investigation. Our outcomes will provide these values for any future projects planned on the topic.

Results

The mean age of enrolled patients was 3.295 ± 1.820 years. Out of 100 patients, 36 were females and 64 were male. The mean weight of patients was found to be 11.55 ± 3.52 kg. The mean total duration from induction to LMA removal at the end of the procedure was 11.91 ± 6.086 min with screening for retinoblastoma under anesthesia being the commonest procedure (61%). Rests of the procedures were refraction measurement, suture removal, cataract examination etc., Two patients were excluded from the study and additional two new patients were added for obtaining the missing data. One of these patients had intraoperative laryngospasm, so proper time keeping for Dion's method could not be carried out; the second patient had to be excluded as the anesthetic gas sampling line was kinked and thus Drager algorithm was not able to calculate the volume of sevoflurane consumed.

The amount of total sevoflurane consumed in each case was calculated using Dion's equation and readings from Drager Primus were noted at the end of each case. Thus, a total of 100-paired readings were obtained. Mean value for sevoflurane consumption by Drager algorithm was 9.040 ± 2.741 ml and by Dion's method was 6.4515 ± 2.01558 ml. The histogram in [Figure 1] shows the distribution of differences between the two methods of measurement. The correlation between Dion's method and Drager algorithm is represented in Figure 2. The coefficient of correlation between the two methods was found to be $r = 0.895$ and was highly statistically significant ($P < 0.001$). However, the poor level of concordance between the two methods is evident from [Figure 3] (Bland and Altman Plot), where the average between the two measures is plotted against the differences between them. Of these 100 readings, the mean difference between Drager algorithm and Dion's method was 2.59 ml whereas the limits of agreement between the two tests were between 5.188 ml and −0.008 ml for a 95% confidence interval [Figure 3]. Both methods were able to appropriately identify cases beyond usual consumption (case no. 38, 41); however, the median values also differed by 2.8 ml and the Dion's method showed lesser variability of readings as represented by smaller 95 percentile range [Figure 4]. Thus, on the average the values estimated via Drager algorithm were higher by 2.59 ± 1.299 ml compared to Dion's method. The values of both test results showed a strong correlation, but poor concordance.

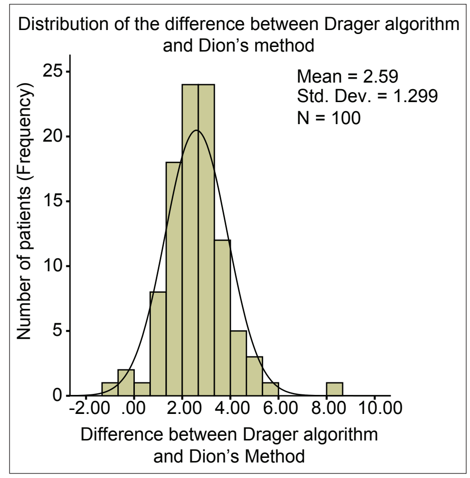

Figure 1: Histogram showing the distribution of difference of two methods (48 of 100 patients had a difference between 2 ml and 4 ml of sevoflurane)

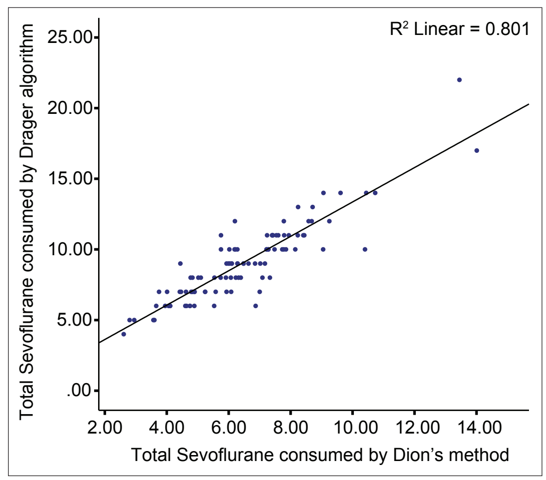

Figure 2: Scatter graph-showing correlation between the two methods. Spearman's Coefficient (0.895)

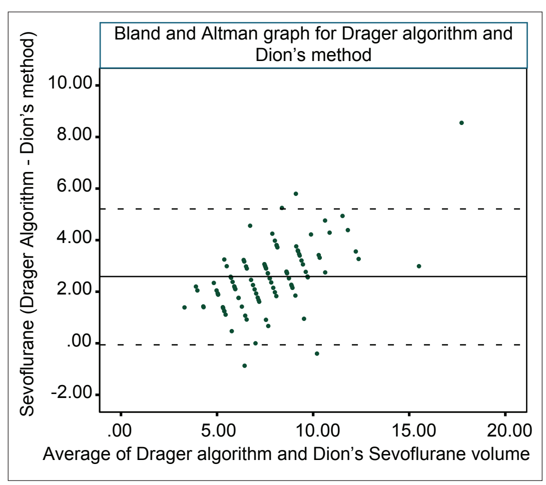

Figure 3: Width (Px): 1201, height (Px): 1038 color depth: Bland and Altman plot between Drager algorithm and Dion's method

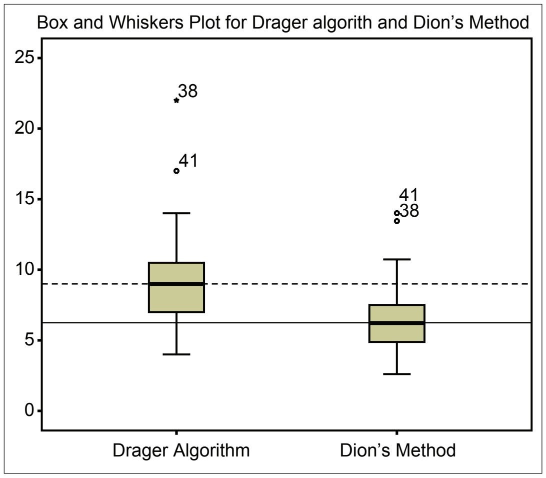

Figure 4: Comparison of median consumption among the two methods (Cases number 38, 41 consumed disproportionately high values of sevoflurane due to prolonged intravenous cannulation duration consuming more gas at higher flow and higher concentration)

Discussion

The present study found a very strong correlation between both methods (correlation coefficient = 0.895, *P*, 0.001); however, the values from both the tests suffer a mean bias difference of 2.59 ml. The use of Dion's method tends to under estimate the usage of inhalation agent probably due to the non-ideal gas behavior of anesthesia volatile agents,[5,6] which is against the basic assumption in the derivation of Dion's equation. Furthermore, the Dion's equation was derived for temperature of 21°C;[4] however in pediatric/infants patients like in our study, the operating room temperature used is higher than this, which could also be cause of the observed bias. At 0°C the denominator in Dion's equation in 2240, which is the molar volume of gas at this temperature, at 21°C the molar volume is 2412 and as the temperature increases the denominator in the equation increases, decreasing measured amount of gas. Furthermore, the time noted at each dial concentration was carried out manually and was in seconds, hence we cannot fully eliminate the possibility of small manual error in this. Drager protocol being automatic measurement is unlikely to suffer from such limitations. Drager algorithm on the other hand can possibly be affected by all errors associated with anesthesia gas monitoring.[7]

Unlike all other anesthetic drugs whose consumption can be easily and accurately measured, inhalation agents face practical limitations of estimation of use.[8] Conventionally weighing the vaporizer before and after use has been used,[9] but such sensitive measuring devices are not commonly available at most hospitals. Weighing after each case may also have constraints of time, equipment sensitivity and cost. Thus, weight based inhalation agent consumption estimates are not universally available and acceptable.

The dragger proprietary algorithm in Drager's own words in their filed patent uses steps of: "Integrating determined anesthetic gas volume flows over a pre-given time interval, determining a quantity of the anesthetic agent consumed over the pre-given time interval from the sum of anesthetic gas volume in the ventilation system."[10] This method also does not need any special equipment for the measurement of consumed agent. An additional advantage of this method is that it can also measure the actual amount of agent uptake by patient. We did not make any comparisons for uptake values as Dion's method cannot calculate such variables. Drager in their filed patent approve of validating their method against actual physical measurement of vapor consumption and report a high degree of accuracy. A patent gas sampling line is a must for the accuracy of this system and it works on calculations of gas concentration in the breathing circuit. However, presently at the time of writing, no clinical investigation is available validating the use of this method for measurement of liquid agent consumed.

Many reports exist on application of Dion's method for calculating consumed amount of inhalation agent used.[11,12] The equation is a logical extension of an ideal gas laws used in physics. It assumes that anesthetic vapors behave as ideal gases, which in actual practice is not true. The formula thus is likely to be associated with error in estimation. Merit of Dion's method is its simplicity and usability in routine operating room setting. In the present study, we used an observer to note the time duration for particular dial settings at a particular fresh gas flow, which added, to need of an additional staff for each case. However, if the method is found to be sufficiently accurate, owing to its simplicity adding its protocol formulae into anesthesia workstation for making automatic calculations is not likely to raise the cost of the system. It can thus be used routinely to evaluate pharmaco-economic aspects of inhalational anesthesia.

Contrasting both protocols Dion's method measures the agent released at the level of vaporizer without any actual physical measurement of concentration or the agent. Thus, it is solely dependent on accuracy of time duration noted, dial concentration and fresh gas flows during the measurements. Drager protocol on the other hand measures real time concentration from the breathing circuit from the Y end. It is not uncommon to have blockage (water) or kinking of the sampling line thus affecting the accuracy of measurement using this method. Both these methods have a practical advantage of not requiring any special equipment for measuring consumed amount of volatile anesthetic agent.

The present study is limited by the absence of previous literature comparing either of the methods to the gold standard "weighing of vaporizer," however our aim was only to evaluate the relation of the two commonly accessible methods of inhalation agent consumption estimation. The fact is that Drager's algorithm is patented to "Drager Inc" and is not available in any other anesthesia workstations. Until newer alternatives are available on other machines, Dion's method can be incorporated to measure the consumed inhalation agents. In anesthesia workstations (older versions and with no automatic gas consumed estimation), Dion's method can be used to estimate inhalation agent consumption with a fair degree of accuracy; however, it must be kept in mind that it may tendto underestimate the consumption. The newer machines can incorporate automatic Dion's protocol with modifications addressing the possible underestimation associated with this method.

Conclusion

Both test results showed a strong correlation, but poor concordance. Drager protocol is patent to Drager Inc. and is not available to other machines however Dion's method with slight modification can be electronically incorporated in other workstations to overcome limitations of real-time measurement of inhalation agent consumption.

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