

Nitrous oxide for monitoring fluid absorption in volunteers[†]

D. Piros, D. Drobin and R. G. Hahn*

Department of Anesthesiology, Karolinska Institute at South Hospital, Stockholm, Sweden

*Corresponding author: Department of Anesthesiology, Karolinska Institute, South Hospital, S-118 83 Stockholm, Sweden. E-mail: r.hahn@telia.com

Background. We studied whether nitrous oxide (N₂O) added to a fluid allows the infused volume to be quantified by measuring N₂O in the expired air during normal breathing. If so, N₂O might serve as a tracer of fluid absorption during endoscopic surgery.

Methods. Twelve male volunteers received continuous and intermittent i.v. infusions (5–45 min) of fluid containing 40 ml litre⁻¹ of N₂O. Breath N₂O and CO₂ concentrations were measured every second via a flared nasal cannula, a standard nasal cannula, or a Hudson mask.

Results. An expression for the amount of infused fluid was obtained by calculating the area under the N₂O concentration–time curve for samples representative for exhalation (CO₂>median) and then dividing this area by the median CO₂ for the remaining samples. The N₂O method then estimated fluid volumes of between 50 and 1400 ml within a 95% prediction interval of ±200 ml. There were differences of up to 14% in results between the airway devices tested, but the volunteers preferred the flared nasal cannula. N₂O showed a distinctly higher 3 min variability during intermittent infusion, which could indicate whether fluid absorption is directly intravascular or extravascular. No adverse effects were seen.

Conclusions. N₂O method does not require forced end-expiratory breath sampling but still predicts an administered fluid volume with high precision. N₂O variability can probably be used to distinguish immediately between intravascular and perivesical fluid absorption during surgery.

Br J Anaesth 2007; **98**: 53–9

Keywords: complications, hyponatraemia; ethanol; fluids, irrigating; measurement techniques, endoscopy

Accepted for publication: August 14, 2006

Endoscopic procedures of the genitourinary tract are usually performed using an irrigating fluid containing glycine, mannitol or sorbitol to constantly rinse blood and pieces of cut tissue out of the operating field. This fluid is occasionally absorbed in volumes of 3–4 litres that give rise to overt and potentially life-threatening symptoms summarized as the ‘transurethral resection (TUR) syndrome’ which has been best described after transurethral resection of the prostate (TURP)^{1,2} and transcervical resection of the endometrium (TCRE).³ However, TUR syndrome is most often incomplete and develops in response to absorption of between 1 and 2 litres of irrigant, which occurs in between 1% and 10% of the TURPs performed.^{4,5} A recent review is available.⁶

There is no generally adopted method for immediate detection of fluid absorption. Measuring fluid output and input or weighing the patient need to be performed meticulously to be reasonably accurate.^{7,8} Another approach is to

add ethanol to the irrigating solution and to use a commercial exhaled ethanol analysed to indicate fluid absorption.^{9,10}

The purpose of this study was to evaluate, in volunteers, the principles of a novel on-line method for monitoring fluid absorption based on adding a trace amount of nitrous oxide (N₂O) to the irrigating fluid. This gas is well known, is chemically inert, has low toxicity and can be measured even at very low concentrations. The amount of infused fluid was to be quantified by measuring N₂O concentration in the expired air. We hypothesized that accurate results can be obtained without active exhalation and that the rapid elimination of N₂O gives a distinctly different temporal profile of data during continuous and intermittent infusions, which can help to distinguish between direct i.v. and

[†]Declaration of interest. Following completion of the study, the sponsors (AGA-AB) gave the patent of the N₂O method to the corresponding author.

extravascular absorption (extravasation). The amount of N₂O required is so small that adverse effects are quite unlikely.

Materials and methods

Twelve healthy male volunteers, aged 19–52 (median, 26) yr and with a body weight of 65–88 kg (median, 76), gave their oral informed consent to participate in the study, which had been approved by the Ethics Committee of Human Research in Southern Stockholm.

All volunteers completed four experiments aimed at evaluating different aspects of monitoring the administration of fluid by means of expired-breath tests using N₂O as a tracer. They were (i) comparing sampling sites, (ii) continuous infusion, and (iii) intermittent infusion using a low N₂O concentration (40 ml litre⁻¹) and (iv) a high N₂O concentration (100 ml litre⁻¹).

Procedure

Volunteers had a light breakfast at home and were not allowed to eat or drink during the experiments, before which they rested supine for 20 min to reach a haemodynamic steady state. A cannula was placed into the antecubital vein of the left arm for fluid infusion to which N₂O for medical use (AGA Linde Healthcare AB, Sundbyberg, Sweden) had been dissolved under sterile conditions shortly (at the most 30 min) before each experiment. The N₂O was taken from a gas tube and withdrawn via a 3-way infusion set into a 250 ml graded glass syringe, which was sterilized daily. The valve on the infusion set was then switched, and the withdrawn gas injected manually through a bacterial filter and a sterile needle into the irrigating fluid via the injection port.

The following four series of experiments were performed on separate occasions at least 2 days apart except for the evaluation of sampling sites, which was performed shortly after Experiment 3. All randomization was made by sealed envelopes.

Comparing sampling sites (84 infusions)

The volunteers received seven 5 min continuous i.v. infusions of lactated Ringer's solution containing 40 ml litre⁻¹ of N₂O. Infusions were administered at a constant rate of 1 ml kg⁻¹ over 5 min with the aid of infusion pumps (Flo-Guard 6201, Baxter Healthcare Ltd, Compton, UK).

During spontaneous ventilation, the N₂O concentration was measured, in random order, from a flared nasal cannula, a standard nasal cannula and a Hudson mask. These experiments were repeated while oxygen therapy was administered through a separate flared nasal cannula at a constant rate of 2 litres of O₂ min⁻¹. In addition, specific recordings were made every 30 s at the end of forced exhalations.

The N₂O was added to Ringer's since hyponatraemia and breath ethanol levels were not assessed.

Continuous infusion

Forty millilitres of N₂O were added to each litre of a standard electrolyte-free irrigating fluid containing mannitol 3% and ethanol 1%, which has an osmolality of 400 mOsm kg⁻¹ and pH 6.0 (Baxter Medical AB, Kista, Sweden). Infusion was given at a constant rate of 15 ml kg⁻¹ over 20 min with the aid of infusion pumps to each volunteer. The total infused volume was 1146 (110) ml [mean (SD)].

Intermittent, low N₂O

The 12 volunteers were randomized to receive one of three intermittent patterns of infusion of the standard irrigating fluid which contained 40 ml litre⁻¹ of N₂O. The infusion patterns were selected to represent low, intermediate and high-rate direct intravascular absorption. The amounts of fluid administered were 7.5, 12 and 15 ml kg⁻¹.

Intermittent, high N₂O

The procedure for the low N₂O concentration experiment was repeated with the exception that the irrigating fluid contained 100 ml litre⁻¹ of N₂O. To still provide the same amount of gas, the infused fluid volume was adjusted to be 40% of the 'low N₂O' experiment.

Measurements continued until the N₂O concentration had returned to baseline, which occurred about 10 min after the administration of N₂O had ended. However, in Experiment 2 the volunteers were followed for 100 min to allow a follow-up of the fluid balance to be made.

Rationale for the experiments

The continuous infusions were intended to simulate extravasation. Intraperitoneal infusions of N₂O-containing irrigating fluid in pigs show that a continuous pattern of breath N₂O develops,¹¹ similar to that when ethanol is used as a tracer.¹²

The intermittent infusions mimicked absorption of irrigating fluid by the direct i.v. route during intermittent filling of the bladder, as such absorption can only occur in bursts whenever the pressure exceeds the prostatic venous pressure of about 1.5 kPa.¹³ The three intermittent infusion patterns used are based on actual absorption cases from our clinic in which the pressure in the bladder and fluid uptake had been measured simultaneously.¹⁴ The same data have been used previously for simulation purposes.¹⁵

A maximum amount of 600 ml of N₂O can be dissolved in 1 litre of water at room temperature.¹⁶ Mixing is facilitated by letting the gas diffuse through the fluid. A bubble is created in the upper part of the fluid bag, which consists mainly of displaced N₂, with which irrigating fluid is always saturated. The present concentration of only 40 ml litre⁻¹ was chosen because concentrations exceeding 100 ml litre⁻¹ might increase a theoretical risk of explosion during electric cutting. N₂O mixes with gases formed during electric cutting, such as propane, which can gather in air pockets within the area of surgery.^{17 18}

Measurements

During all experiments, routine monitoring comprised pulse oximetry and non-invasive blood pressure. The N₂O and CO₂ concentrations in the exhaled breath were measured every second by an N₂O monitor (NGA 2000 MLT Analyzer, Rosemount Analytical, Hasselroth, Germany), which consists of a temperature-controlled 30 ml sampling unit with pump valves. Gas concentrations are measured by an absorbance technique using infrared signals which do not interfere with each other. For N₂O, the range was 5–2000 ppm. The pump was set to a suction rate of 300 ml of air per minute and sampling was performed via a flared nasal cannula (Hudson Respiratory Care Inc., Temecula, CA, USA) except in Experiment 1, in which different sampling devices were tested. Data were stored directly on a laptop computer until N₂O levels had returned to baseline.

In Experiments 2 and 3, the end-expiratory ethanol concentration was measured every 5 min. The volunteer was asked to take a deep breath and perform a single end-expiratory breath alcohol test using a Lion Alcolmeter S-D2 (Lion laboratories, Wales, UK) at 0, 5, 10, 20, 30, 40, 50, 60, 80 and 100 min. Blood samples (9 ml) were drawn on the same occasions from a separate i.v. cannula, placed in the antecubital vein of the right arm, for measurement of the blood Hb and serum sodium concentrations. Hb was analysed on a Technicon H2 (Bayer, Tarrytown, NY, USA) and electrolytes on a Hitachi Modular (Hitachi Hi-Tech Corp., Tokyo, Japan).

Calculations

Nitrous oxide

Adjustments of N₂O output for CO₂ level were made to account for different breathing patterns and admixture with ambient air. In the series of 12 continuous infusions, several ways of minimizing the variability in N₂O were tested and compared, and we arrived at the following approach. For the end of each 5 min interval of these 12 experiments, the individual area under the concentration curve (AUC) for N₂O was calculated based on the samples in which the CO₂ was above the median value. The reason for discarding all values associated with a low CO₂ concentration was to ensure that only the most representative data for exhalation were included. This AUC for N₂O was then divided by the median CO₂ for the remaining sampling points. This algorithm was then applied in all 120 experiments, and its ability to predict the infused fluid volume evaluated by residual plots for each series.

To make the low- and high-concentration experiments comparable, fluid volumes used in the latter were too low and therefore multiplied by 2.5 to compensate for the difference in N₂O content between infusions.

Ethanol

For the ethanol-monitoring method, the absorbed volume over 10 min was calculated using the following previously published equation, derived during TURP:¹⁹

$$\text{Volume}_{\text{Abs}} = \sum [(2140 + 3430 * \text{Ethanol}) * \Delta \text{Ethanol}] \\ * (44 + 806 * \text{Ethanol})$$

where Volume_{Abs} is the predicted incremental volume of absorbed fluid (ml), Ethanol is the blood ethanol concentration (mg ml⁻¹) as indicated in the breath at the beginning of a 10 min interval, and ΔEthanol is the change in concentration during the same 10 min interval.

Statistics

Results were expressed as the mean (SD). Correlations were evaluated by linear regression analysis and the differences between sampling sites by repeated-measures ANOVA. Changes from baseline were studied by repeated-measures ANOVA followed by Dunnett's test. AUC was calculated by the linear trapezoid method. The coefficient of variation (CV) for breath N₂O was obtained as SD divided by the mean over time. CV was recalculated every 30 s, and the Wilcoxon test was used to compare results between continuous and intermittent infusions. *P*<0.05 was statistically significant.

Results

No adverse events occurred. There were fairly small but still statistically significant differences in the CO₂-adjusted AUC for the N₂O concentration depending on whether sampling was done from a flared nasal cannula (reference), a standard nasal cannula (+14%) or a Hudson mask (+8%). Adding O₂ via a flared nasal catheter marginally changed the AUC obtained via any of these airway devices (Fig. 1). In contrast, end-expiratory sampling yielded a 25% lower value (*P*<0.001). All volunteers agreed that the flared nasal cannula was the most comfortable sampling method.

The individual N₂O time–concentration profiles had a different appearance depending on the mode of infusion (Fig. 2A). Quite variable patterns were used for the three intermittent infusions (Fig. 2B). The CV for the N₂O concentration over 3 min intervals was much higher for the intermittent than the continuous infusions (mean 0.70 vs 0.26, *P*<0.001; Fig. 3). The 3 min interval was the shortest that still offered an excellent distinction between the two types of infusions.

The CO₂-adjusted AUC for N₂O did not differ significantly when the fluid volume in the high-dose experiment was multiplied by 2.5, i.e. the factor with which the N₂O concentration differed between low- and high-dose experiments. The results are therefore presented together in Figure 4, which show that the AUC strongly correlated with the volume of infused N₂O-containing irrigating fluid, regardless of whether the fluid was infused continuously or intermittently with a high or low N₂O concentration. The

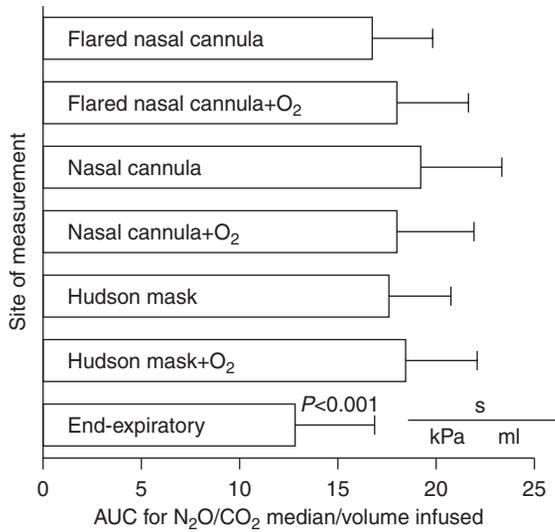


Fig 1 CO₂-adjusted area under the curve (AUC) for N₂O concentration per infused fluid volume at the end of a 5 min infusion of 1 ml kg⁻¹ of lactated Ringer's solution containing 40 ml litre⁻¹ of N₂O. Each bar represents the mean (SD) for 12 volunteers.

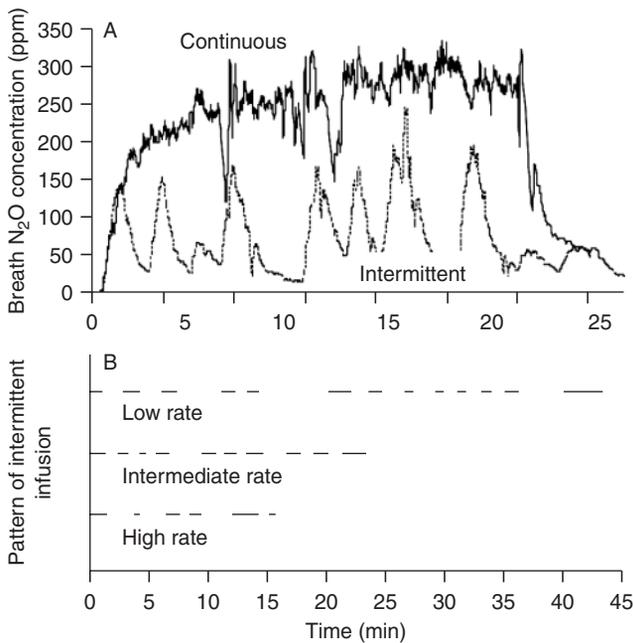


Fig 2 Breath N₂O concentration over time during a continuous and an intermittent infusion of an irrigating fluid containing 40 ml litre⁻¹ of N₂O. Continuous infusion concentrations increase towards a steady-state while intermittent infusions yield a pattern with bursts and plateaus (A). Intervals and duration of the intermittent infusions (B).

95% prediction interval was ±200 ml, and overall the data showed a normal distribution around the regression line (Fig. 5A).

Breath ethanol concentrations obtained during the continuous and intermittent infusions of irrigating fluid (Fig. 6B) slightly overestimated the known infused fluid volume. The 95% prediction interval was approximately

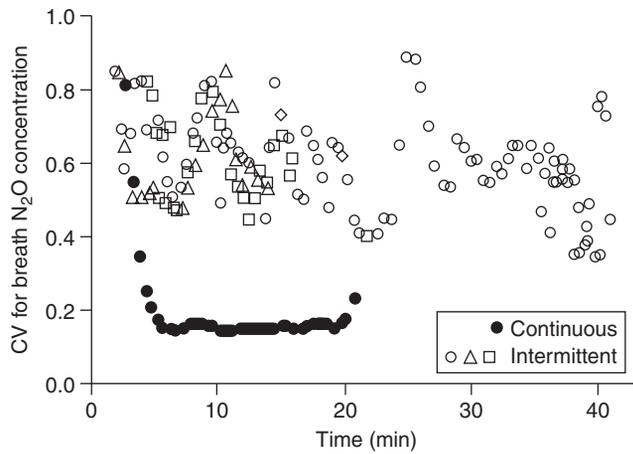


Fig 3 Coefficient of variation (CV, no unit) over time for N₂O concentration in expired air during continuous (closed circles) and intermittent (open symbols) infusions. Each point is the mean of 12 (closed) and 4 experiments (open symbols). Different shapes of open symbols show whether the infusion was given at a low, intermediate, or high rate over 45, 24 and 16 min, respectively.

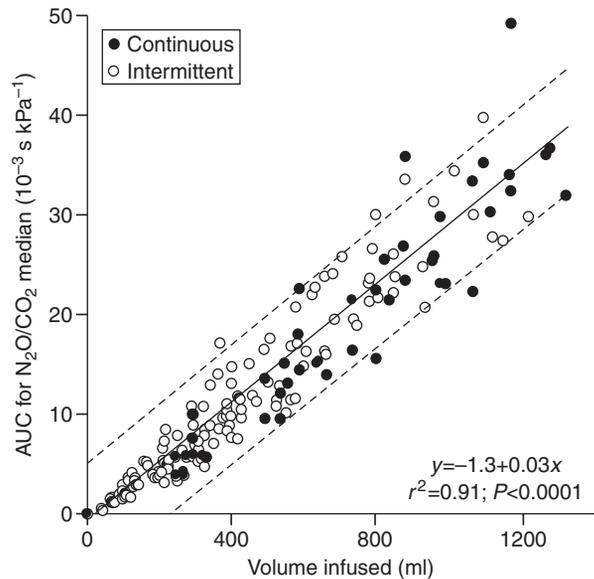


Fig 4 CO₂-adjusted area under the curve (AUC) for N₂O concentration vs volume of infused fluid in 12 volunteers receiving continuous and intermittent i.v. infusions of N₂O-containing irrigating solution. Best fit and the 95% prediction interval for all observations at the end of each 5 min period is indicated.

400 ml (Fig. 6B) which is in agreement with previous findings based on a larger number of data points.¹⁰

Blood Hb and serum sodium concentrations decreased by 6% during the continuous-infusion experiments (repeated-measures ANOVA, *P*<0.001), but only Hb was restored during the follow-up period.

Discussion

The study evaluated whether it would be possible to monitor i.v. fluid administration by adding a tracer amount of N₂O to

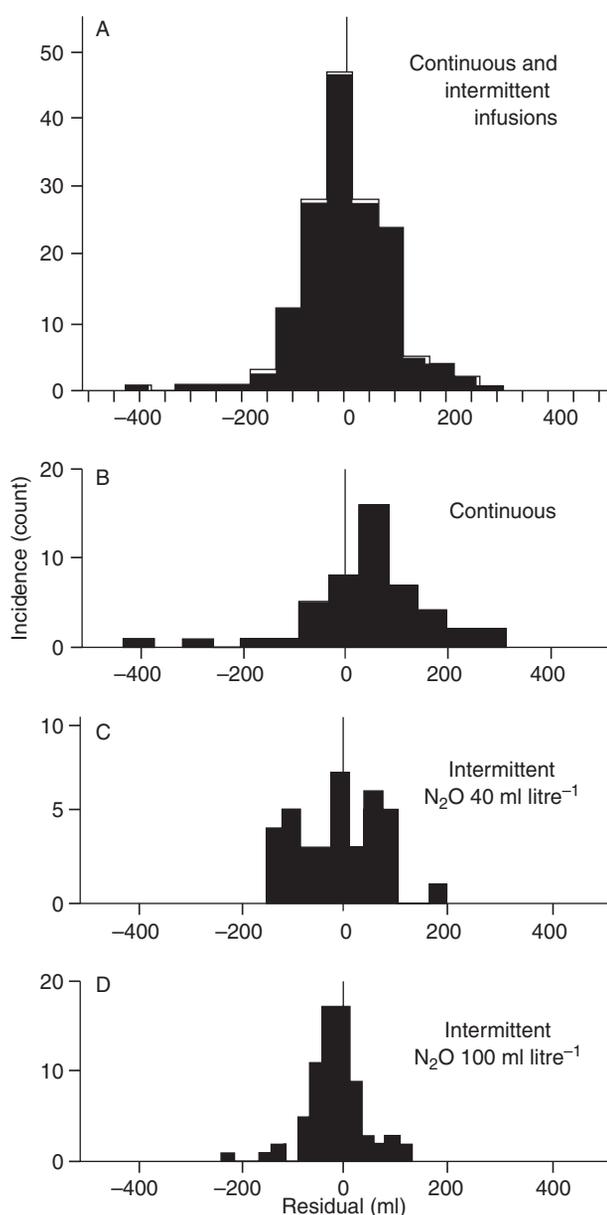


Fig 5 Residuals obtained when fitting a linear regression equation to the relationship between N₂O and infused volume, as shown in Figure 4, at the end of each 5 min period during continuous and intermittent infusions together and separately.

the fluid and sampling exhaled air during normal breathing. An algorithm was developed based on 12 of the 120 experiments, and eventually validated on all of them by demonstrating limited scattering on residual plots (Fig. 5). This algorithm adjusted the N₂O data with regard to the depth of breathing and also removed measurements performed during apparent inhalation. Since the AUC for a drug changes in proportion to the dose, we finally used the CO₂-corrected AUC for N₂O concentration as the expression for infused fluid volume. The correlation between N₂O and infused volume then became linear and, when applied to all experiments, the 95% prediction interval for any new measurement was only ± 200 ml for fluid volumes up to 1400 ml

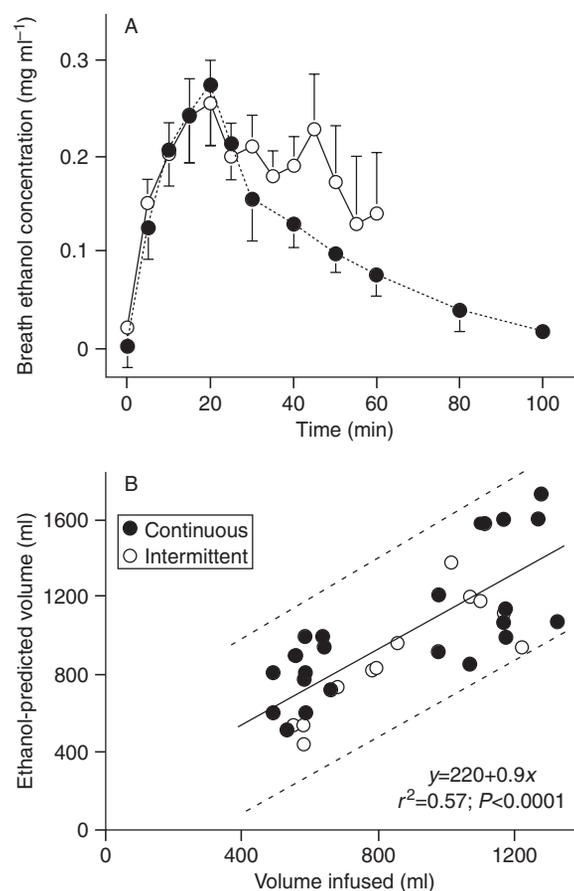


Fig 6 The end-expiratory ethanol concentration [mean (SD)] during continuous and intermittent infusions of irrigating fluid containing mannitol 3% and ethanol 1% (A). Volume of infused fluid calculated using a regression equation based on the pattern of breath ethanol levels vs the actual infused volume (B).

(Fig. 4). However, one must consider that the regression line describing the correlation between N₂O and the actually infused fluid volume is valid only for the measuring chamber size of 30 ml and a suction rate of 300 ml min⁻¹. The slope is likely to be slightly different with other settings.

The precision of this measurement was slightly influenced by whether breath sampling was performed via a flared nasal cannula, a standard nasal cannula, or a Hudson mask. However, since the volunteers preferred the flared nasal cannula, we concluded that further experiments should be performed using this airway device. Moreover, the results were affected only marginally by simultaneous administration of oxygen, which might be important in the operating theatre. End-expiratory sampling, however, yielded lower values than the three modes of continuous measurement. This might be explained by the fact that the measuring chamber for N₂O is larger than that for CO₂. The N₂O chamber then partially equilibrates the concentration over time which yields a falsely low peak at the end of exhalation. The volunteers also had difficulty in providing a forced end-expiratory sample every 30 s, which probably made this mode of measuring less accurate.

The N₂O technique could serve as a monitoring tool when administration of fluid may occur spontaneously in unknown volumes, such as fluid absorption during endoscopic surgery. A prerequisite would be that N₂O does not diffuse through the mucosa of the urinary tract. Such diffusion was not found in pigs studied prior to these experiments (R. Hahn, unpublished data). The tracer also needs to be absorbed in the same proportion as the irrigating fluid. This is well studied for ethanol,¹⁰ and a completed but yet unpublished two-centre clinical trial shows that it is also the case for N₂O during TURP. Immediate detection of fluid absorption on the operating table is of clinical value as it allows steps to be taken to prevent excessive absorption. Monitoring allows the earliest possible treatment to be instituted and the optimal level of postoperative care be selected. Our goal is to automate the calculations and have the results displayed continuously to the operating team.

Fluid absorption is rarely monitored in the operating theatre because of the poor precision or invasiveness of the available methods. In the volunteers, Hb and serum sodium decreased only by 6% in response to 1.1 litre of fluid. In the operating theatre these blood parameters are affected by factors other than fluid absorption. The most viable approaches are ethanol monitoring and continuous weighing of the patient on a bed-scale.⁹ Both are reasonably accurate, but the latter method can only be applied when the bladder is empty. As for Hb and sodium, the result is confounded by blood loss and i.v. infusion. These drawbacks are not shared by ethanol monitoring, which is in daily use in some European countries. The method is simple and safe but the patient must currently make an active exhalation to provide a breath sample, except in the 10–15% of patients in whom the endoscopic surgery is performed under general anaesthesia.²⁰ Rapid fluid absorption raises blood alcohol sufficient to make the patient legally unfit to drive a car. Elimination from the blood is relatively slow.¹⁰

In contrast, N₂O can apparently be monitored continuously without active involvement of the anaesthetist, the surgeon or the patient. Measuring N₂O during general anaesthesia is a well-known technique and, in the awake patient, this study suggests that N₂O could provide a more precise estimate of fluid absorption than ethanol. The wider prediction interval of ethanol is based on fewer observations but is in agreement with the 90% prediction interval of ± 300 ml obtained for 160 TURPs.¹⁰

Another benefit is that N₂O may distinguish between direct intravascular absorption and extravasation (Figs 2 and 3). The former type is most common during TURP^{4,5} and TCRE²¹ while the latter dominates during renal stone surgery.²² During TURP, intravascular absorption occurs only during the periods of time when the fluid pressure exceeds the periprostatic pressure,¹³ which happens during the latter part of each intermittent filling of the bladder.¹⁴ The fact that no uptake of fluid can occur during the first part of each filling¹⁵ explains why the concentration–time curve

of N₂O in the breath becomes intermittent. In contrast, extravasation implies that fluid is continuously being absorbed from a pool deposited in the periprostatic, retroperitoneal or intraperitoneal space. Here, any elevation of the N₂O concentration is more stable.

Measurements were performed every second, as bursts of fluid might otherwise be missed because of the high clearance of N₂O. Thanks to frequent sampling, the three different patterns of intermittent infusion provided data on N₂O that correlated as well as the continuous infusion with the amount of infused fluid (Fig. 4). However, calculating the CV over 3 min yielded a clear difference between the two types of fluid administration (Fig. 3). While not tested in this study, extravasation results in N₂O, ethanol and serum sodium responses that are only one-third of those found after intravascular absorption.^{10,11} Dangerous symptoms may develop before treatment is started if extravasation is mistaken for intravascular absorption.²³

The concentrations of N₂O reached in the present study are within the environmental pollution range (0–500 ppm). Dissociative mental effects of N₂O occurs at a concentration >25%, which is 1000 times higher than the maximum concentrations measured in the present experiments (Fig. 2). However, the patient's brain is exposed to even lower concentrations since mass balance calculations based on i.v. infusions of N₂O in anaesthetized pigs indicate that nearly all gas is eliminated during the first passage through the lungs.¹¹ This massive first-pass elimination probably makes accumulation of gas in the intestines unimportant. Exhaled N₂O is quickly diluted in the ambient air, and any elevated concentration soon becomes impossible to detect. Needless to say, implementation of the method described in the clinic precludes the use of N₂O as an adjunct to general anaesthesia.

After conclusion of the present experiments, a laboratory study revealed that N₂O escapes from plastic fluid bags at a rate of 5% per hour (unpublished data). For clinical use, we believe that the N₂O should be added to the fluid immediately before use via a small gas bomb attached to a port on the irrigating system. This arrangement would also prevent the need for more types of factory-made irrigating fluids.

In conclusion, the results from an i.v. infusion study in volunteers suggest that N₂O can serve as a tracer for irrigating fluid absorption in patients undergoing endoscopic surgery. Potential benefits include practical aspects of monitoring, good precision and low toxicity. Further studies during actual surgical interventions are needed to evaluate whether these findings are also valid in clinical practice.

Acknowledgement

The study was sponsored by AGA Linde Healthcare AB, Lidingö, Sweden.

References

- 1 Osborn DE, Rao PN, Greene MJ, Barnard RJ. Fluid absorption during transurethral resection. *Br Med J* 1980; **281**: 1549–50
- 2 Rothenberg DM, Berns AS, Ivankovich AD. Isotonic hyponatremia following transurethral prostate resection. *J Clin Anesth* 1990; **2**: 48–53
- 3 Baggish MS, Brill AIO, Rosenweig B, Barbot JE, Indman PD. Fatal acute glycine and sorbitol toxicity during operative hysteroscopy. *J Gynecol Surg* 1993; **9**: 137–43
- 4 Olsson J, Nilsson A, Hahn RG. Symptoms of the transurethral resection syndrome using glycine as the irrigant. *J Urol* 1995; **154**: 123–8
- 5 Hahn RG, Sandfeldt L, Nyman CR. Double-blind randomized study of symptoms associated with absorption of glycine 1.5% or mannitol 3% during transurethral resection of the prostate. *J Urol* 1998; **160**: 397–401
- 6 Hahn RG. Fluid absorption in endoscopic surgery (review). *Br J Anaesth* 2006; **96**: 8–20
- 7 Boyd HR, Stanely C. Sources of error when tracking irrigation fluids during hysteroscopic procedures. *J Am Assoc Gynecol Laparosc* 2000; **7**: 472–6
- 8 Hahn RG. The volumetric fluid balance as a measure of fluid absorption during transurethral resection of the prostate. *Eur J Anaesth* 2000; **17**: 559–65
- 9 Shipstone DP, Inman RD, Beacock CJM, Coppinger SWV. Validation of the ethanol breath test and on-table weighing to measure irrigating fluid absorption during transurethral prostatectomy. *BJU Int* 2002; **90**: 872–5
- 10 Hahn RG. Ethanol monitoring of irrigating fluid absorption (review). *Eur J Anaesth* 1996; **13**: 102–15
- 11 Hahn RG. Nitrous oxide as a marker for irrigating fluid absorption. An experimental study in the pig. *Scand J Urol Nephrol* 2003; **37**: 281–5
- 12 Olsson J, Hahn RG. Simulated intraperitoneal absorption of irrigating fluid. *Acta Obstet Gynecol Scand* 1995; **74**: 707–13
- 13 Hultén J, Bengtsson M, Engberg A, Hjertberg H, Svedberg J. The pressure in the prostatic fossa and fluid absorption. *Scand J Urol Nephrol* 1984; **82** (Suppl.): 33–43
- 14 Hahn RG, Berlin T, Johansson H, Lewenhaupt A. Changes in intravesical pressure during irrigating fluid absorption in transurethral prostatic surgery. *Urol Res* 1988; **16**: 281–5
- 15 Hahn RG, Larsson H, Ribbe T. Continuous monitoring of irrigating fluid absorption during transurethral surgery. *Anaesthesia* 1995; **50**: 327–31
- 16 *Gas Encyclopaedia*. Elsevier Scientific Publishing Company, 1976; 1056
- 17 Ning TC, Atkins DM, Murphy RC. Bladder explosion during transurethral surgery. *J Urol* 1975; **114**: 536
- 18 Iversen Hansen R, Iversen P. Bladder explosion during uninterrupted transurethral resection of the prostate. *Scand J Urol Nephrol* 1979; **13**: 211–2
- 19 Hahn RG. Calculation of irrigant absorption by measurement of breath alcohol level during transurethral resection of the prostate. *Br J Urol* 1991; **68**: 390–3
- 20 Stalberg HP, Hahn RG, Jones AW. Ethanol monitoring of transurethral prostatic resection during inhalation anesthesia. *Anesth Analg* 1992; **75**: 983–8
- 21 Olsson J, Hahn RG. Ethanol monitoring of irrigating fluid absorption in transcervical resection of the endometrium. *Acta Anaesthesiol Scand* 1995; **39**: 252–8
- 22 Gehring H, Nahm W, Zimmermann K, et al. Irrigating fluid absorption during percutaneous nephrolithotripsy. *Acta Anaesthesiol Scand* 1999; **43**: 316–21
- 23 Hahn RG. Life-threatening transurethral resection syndrome despite monitoring of fluid absorption with ethanol. *Eur J Anaesth* 1995; **12**: 431–3