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Desflurane consumption with automated vapour control systems in two different anaesthesia machines. A randomized controlled study

Dagmar Mostad[1] | Pål Klepstad[1,2] | Turid Follestad[3] | Hilde Pleym[1,2]

[1]Clinic of Anaesthesia and Intensive Care, St. Olav's University Hospital, Trondheim, Norway

[2]Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, NTNU, Trondheim, Norway

[3]Department of Clinical and Molecular Medicine, Norwegian University of Science and Technology, NTNU, Trondheim, Norway

Correspondence
Dagmar Mostad, Department of Anaesthesia and Intensive Care, St. Olav's University Hospital, N-7006 Trondheim, Norway.
Email: Dagmar.Heinke.Mostad@stolav.no

Abstract

Background: In general anaesthesia practice a fresh gas flow (FGF) of ≥0.5 L/min is usually applied. Automated gas delivery devices are developed to reduce volatile anaesthetic consumption by limiting gas flow. This study aimed to compare desflurane consumption between automated gas control devices compared to conventional low flow anaesthesia in the Flow-I and Aisys anaesthesia machines, and to compare desflurane consumption between the two automated gas delivery devices. We hypothesised that desflurane consumption would be lower with automated gas delivery compared to conventional low flow anaesthesia, and that desflurane consumption could differ between the different gas delivery devices.

Methods: We allocated 160 patients undergoing robot-assisted laparoscopic surgery into four groups, Flow-I with automated gas control, Flow-i with conventional low-flow (1 L/min), Aisys with end tidal gas control and Aisys with conventional low flow. Patients were maintained at minimum alveolar concentration (MAC) 0.7-0.8. Desflurane consumption was recorded after 9, 30 and 60 minutes of anaesthesia.

Results: After 60 minutes, compared to conventional low flow anaesthesia, automated gas delivery systems reduced desflurane consumption from 25.8 to 15.2 mL for the Aisys machine ($P < .001$) and from 22.1 to 16.8 mL for the Flow-I ($P < .001$). Time to MAC 0.7 and stable FGF was shorter with Aisys endtidal control compared to Flow-I automated gas control.

Conclusion: Under clinical conditions, we found a reduction in desflurane consumption when using automated gas delivery devices compared to conventional low flow anaesthesia. Both devices were reliable in use.

Editorial Comment

The delivery of volatile anesthetics by anesthesia machines is dependent on fresh gas anesthetic concentration and fresh gas flow. These findings demonstrate that the amount of desflurane during conventional low flow anaesthesia can be reduced further by utilizing automated gas delivery control systems.

1 | INTRODUCTION

Baker's modified classification defines low flow anaesthesia as fresh gas flow (FGF) rates in anaesthetic circuits <1 L/min.[1] The advantages of low (0.5-1 L/min) and minimal (0.25-0.5 L/min) flow general anaesthesia are well known,[2-8] yet use of higher flows is still common. Advantages with the use of low flow general anaesthesia are reduced loss of heat and moisture[9-13] and reduction in consumption of volatile anaesthetics, which is important for both economic and environmental reasons.[9] Despite that low flow anaesthesia has been utilised for several decades, anaesthesia with a gas flow >1 L/min is still in use.[7,10,13] Reasons for FGFs >1 L/min may be fear of patient awareness, or lack of training in low or minimal flow anaesthesia.

The manufacturers of anaesthesia machines have introduced automated gas control devices constructed to deliver stable oxygen and volatile anaesthetic concentrations during anaesthesia. The devices ensure safe delivery of volatile anaesthetics and oxygen during low or minimal flow anaesthesia.[14] However, since the introduction of automated gas control delivery systems only a few studies have investigated functionality and effects on volatile anaesthetic consumption.[14-20]

The aim of this study was to compare the consumption of desflurane delivered with and without the use of automated gas control (AGC) Flow-I or end-tidal gas control Aisys gas control delivery systems. We also compared volatile anaesthetic consumption between the two different automated anaesthetic gas control systems used in the study, the time it took to reach a minimum alveolar concentration of 0.7 and the time to reach a FGF of 0.5 L/min. We hypothesised that both gas delivery devices would reduce desflurane consumption compared to traditional low flow anaesthesia. In addition, we hypothesized that due to the different algorithms in the two gas delivery devices, the desflurane consumption during anaesthesia could differ between the devices.

2 | METHODS

2.1 | Ethics

The study was a single centre, prospective, randomized study performed at St. Olav's University Hospital, a 737-bed referral hospital. The Regional Ethics Committee of the Health Region South-East, Norway considered the investigation as a quality control study according to Norwegian law (Act on medical and health research, §§ 2 and 4), and had no objections against the study (REK 2015/2132, 17.12.2015). The data protection officer of St. Olav's University Hospital in Trondheim approved the study (ESA 16/1920-6, 24.02.2016). The study is registered in ClinicalTrials.gov (NCT02774031, 16.05.2016). All patients gave oral and written informed consent prior to the study.

2.2 | Patients

Patients scheduled for robot-assisted laparoscopic prostatectomy, robot-assisted laparoscopic cystectomy, or robot-assisted laparoscopic gynaecological surgery were screened for inclusion by a single anaesthesiologist (DM). Patients with cognitive failure which compromised the ability to give informed consent, pregnancy, age under 18 years or American Society of Anaesthesiologists' physical status classification system (ASA) IV-V, were not eligible for the study. Included patients were excluded from the study if surgical problems made it impossible to complete the operation with robot assisted surgery, or due to technical problems with the anaesthesia machine.

2.3 | Randomization

The patients were randomized to one of four groups. The randomization was performed by a web-based randomization system developed and administered by the Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology, Trondheim, Norway (https://www.klinforsk.no).

Group 1 was anaesthetised using the Aisys anaesthesia machine (Aisys, GE Healthcare) with end-tidal (Et) control (Aisys Et-control group). The ventilation mode was pressure controlled ventilation with volume guarantee. Settings for tidal volume (TV), positive end expiratory pressure (PEEP) and respiration rate (RR) were TV 7-9 mL/kg body weight (BW), RR 12-14/min, and PEEP 8-10 cmH_2O. Target for end expired desflurane concentration ($F_A$des) was set to achieve an age adjusted minimum alveolar concentration (MAC) of 0.7-0.8, and target for F_AO_2 was set to 35%.

Group 2 was anaesthetised using the Aisys anaesthesia machine without Et-control (Aisys conventional ventilation group). The ventilation mode was the same as for group 1. After intubation, the patients received a FGF of 5 L/min, and the desflurane vaporizer was set at 6 volume % for 5 minutes. Thereafter the FGF was reduced to 1 L/min and the vaporizer setting was manually adjusted to keep an age adjusted MAC of 0.7-0.8. Oxygen concentration was set to 50%, in accordance with routine practice. A FGF of 1 L/min was chosen, as this is the routine FGF used for low flow anaesthesia in our hospital.

Group 3 was anaesthetised using the Flow-I anaesthesia machine (Flow-I, Maquet) with AGC (Flow-I AGC group). The ventilation mode was pressure regulated volume control with TV 7-9 mL/kg BW, RR 12-14/min, and PEEP 8-10 cmH_2O. Target for $F_A$des was set to achieve an age adjusted MAC of 0.7-0.8, and target for inspired oxygen (F_iO_2) was set to 40%.

Group 4 was anaesthetised using the Flow-I anaesthesia machine without AGC (Flow-I conventional group). The ventilation mode was the same as for group 3. After intubation the patients were given a FGF of 5 L/min, and the desflurane vaporizer was set at 6 volume % for 5 minutes. Thereafter the FGF was reduced to 1 L/min and the vaporizer setting was manually adjusted to keep an age adjusted MAC of 0.7-0.8. Oxygen concentration was set to 50%.

2.4 | Interventions

All patients were treated in accordance with the standard procedure for the relevant operation. This included the use of the DaVinci Robot (Intuitive Surgical), steep Trendelenburg position (30 degrees head down) for at least 1 hour and pneumoperitoneum. Desflurane was chosen as this is the volatile anaesthetic agent used routinely at our department. Likewise, a FGF of 1 L was chosen as this is our standard for low flow anaesthesia.

All patients received oral oxycodone slow release (10mg), oral dexamethasone (8 mg <70 kg or 12 mg >70 kg BW), and oral paracetamol (1.5 g < 70 kg or 2 g > 70 kg BW) 1 hour prior to surgery. Ringer's acetate solution 1000 mL was started after establishing venous access. Propofol 2 mg/kg, fentanyl 0.1-0.15 mg and remifentanil 0.1 μg/kg/min were used for induction of general anaesthesia. A non-depolarizing neuromuscular blocking agent was given to facilitate intubation, with an additional maintenance dose if necessary. Mechanical ventilation was activated immediately after securing the airway. Anaesthesia was maintained with desflurane and a continuous infusion of remifentanil. Desflurane administration was started immediately after mechanical ventilation was started.

Patients undergoing cystectomy received an epidural catheter before induction of general anaesthesia. The epidural analgesia was activated at the start of the surgical procedure. Patients undergoing prostatectomy and gynaecological surgery received a transversus abdominis plane block after induction.

The gas control system in the Aisys machine is based on Et-control of oxygen and the volatile anaesthetic agent.[21] The Et-control feature must be specifically activated. The anaesthesiologist targets the Et oxygen (F_AO2) and Et anaesthetic agent gas concentration ($F_A$agent). At any deviation between measured and set values for oxygen and volatile anaesthetic, the feedback loop of the system will automatically change the FGF, oxygen and volatile anaesthetic delivery to maintain the set values. The default setting for FGF is 0.5 L/min in the Et-control modus. The AGC system in the Flow-I machine must also be activated by the anaesthesiologist.[22] This system controls the oxygen concentration on the inspiratory side of the anaesthetic circuit while the anaesthetic gas concentration is controlled on the expiratory side. The anaesthesiologist targets the inspired oxygen concentration (F_iO_2) and the $F_A$agent. With this device, the anaesthesiologist can also regulate the time it takes to reach the desired target concentrations between 1 and 9, where 1 is the slowest and 9 is the fastest speed. We choose speed 6 in our study. Deviation between measured and set values for oxygen and volatile anaesthetic are regulated via a feedback loop of the system. FGF will automatically change to maintain the set values for oxygen and the volatile anaesthetic agent. The default setting for FGF in the AGC modus is 0.3 L/min.

2.5 | Data collection

The demographic and clinical variables gender, age, BMI and ASA classification were registered. Variables related to surgery were type of surgery and duration of the surgical procedure. Oxygen saturation was monitored during the procedure.

2.6 | Outcome measures

The primary outcome measure was the consumption of desflurane, measured in mL of liquid agent. The consumption was recorded at 9, 30 and 60 minutes after initiation of desflurane delivery. The sampling point at 9 minutes was set based on a study that investigated the wash-in time for desflurane in a test-lung device.[19] The sampling point at 30 minutes were set for the investigation of a possible reduction in gas consumption over time. Secondary outcomes were time to reach MAC 0.7 and time to reach a FGF of 0.5 L/min when using the Flow-I AGC and Aisys Et-control the first 60 minutes. Desflurane consumption data were recorded manually from the anaesthesia machine after 9, 30 and 60 minutes. The time to reach 0.7 MAC and a FGF of 0.5 L/min were recorded manually from the anaesthesia machine immediately after the end of anaesthesia.

2.7 | Statistical methods

Data are summarized as means (SD), medians (range) or frequencies (%) as appropriate. The volatile anaesthetic consumption in the four groups (Aisys Et-control group, Aisys conventional ventilation group, Flow-I AGC group and Flow-I conventional ventilation group) were compared by using linear regression, adjusting for age and gender. Separate linear regression models were fitted for the data at 9, 30 and 60 minutes. Mann-Whitney *U* tests were used to compare the time to reach MAC 0.7 or more between groups and for the time to reach stable FGF in the groups with automatic gas delivery devices. *P*-values <.05 were considered statistically significant. The data were analysed with the SPSS software Version 23 (IBM).

2.8 | Sample size estimation

The determination of the sample size was based on a pilot study in which 10 patients were included. The pilot study showed that the use of Aisys Et-control with a FGF of 0.5 L reduced desflurane consumption by 20%-25% compared to conventional use of the Aisys machine without Et-control and a FGF of 1 L. The estimated SD was 3 mL. We considered a difference in desflurane consumption of 4 mL to be clinically significant. To detect a difference of 4 mL, which corresponds to a 22% reduction from a consumption of 18 mL, between two groups by a two-sample *t*-test, with SD = 3 mL, $\alpha = 0.05$ and a power of 0.80, 10 patients would have had to be included in each of the two groups. Thus, a total of 40 patients would be needed for the two machines and devices. In order to protect against a potential non-normal distribution, potential drop-outs and the adjustment for age and gender in a linear regression model, including 40 patients in each group (a total of 160 patients) was considered to be sufficient.

3 | RESULTS

One hundred and sixty patients were included in the study between April 2016 and March 2017. Thirteen patients were excluded after inclusion (Figure 1). Results from the remaining 147 patients were included in the analyses. Mean age of all patients included in the analyses were 60 (SD: 12) years, 50% were male, median BMI was 26.8, and 9, 103, and 35 patients were ASA 1, 2 or 3 respectively. Baseline patient characteristics and data on surgical procedures for each of the study groups are given in Table 1.

The mean desflurane consumption after 60 minutes were 16.8 (SD: 3.4) mL of liquid agent with AGC, 15.2 (SD: 1.8) mL with Et-control, 22.1 (SD: 1.7) mL without AGC and 25.8 (SD: 1.1) mL without Et-control. All results after 9, 30 and 60 minutes are given in Table 2. There were decreases in desflurane consumption at all time-points when an automated gas delivery device was used compared to conventional low flow anaesthesia. The difference was present for both anaesthetic machines (Table 2). In addition, the use of the Aisys Et-control device resulted in lower desflurane consumption after 9 and 30 minutes of desflurane administration compared to the Flow-I AGC device. However, after 60 minutes there was no significant difference in desflurane consumption between the two anaesthetic machines (Table 3).

The mean time to reach a MAC of 0.7 with automated gas delivery devices was longer with the AGC Flow-I (6.5 (4.7) minutes) than with the Et-control Aisys device (3.6 (2.2) minutes). There was

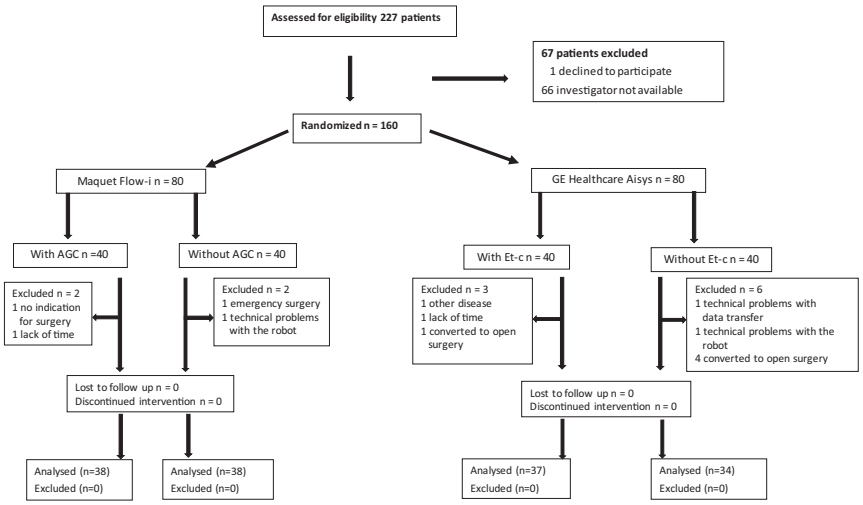

FIGURE 1 Flow chart for included and excluded patients. With AGC, Maquet Flow-I with Automatic gas control device; With Et-c, GE Healthcare Aisys with end-tidal control device; Without AGC, Maquet Flow-I without Automatic gas control device; Without Et-c, GE Healthcare Aisys without end-tidal control device

TABLE 1 Baseline patient characteristics and data of surgical procedures

	All patients	Without AGC	With ACG	With Et-control	Without Et-control
	147	38	38	37	34
Gender m/f	73/74	17/21	26/12	14/23	16/18
Age	60 (12)	59 (11)	62 (12)	63 (14)	59 (11)
BMI	26.8 (18.4-42.7)	27.1 (18.4-42.7)	27.6 (19.3-40)	26.4 (20.3-37)	26.7 (18.4-40.7)
ASA	2 (1-3)	2 (2-3)	2 (2-3)	2 (1-3)	2 (1-3)
ASA 1	9 (6.1%)	0	0	2 (5.4%)	7 (20.6%)
ASA 2	103 (70.1%)	24 (63.2%)	30 (78.9%)	29 (78.4%)	20 (58.8%)
ASA 3	35 (23.8%)	14 (36.8%)	8 (21.1%)	6 (16.2%)	7 (20.6%)
Type of surgery					
Robot prostatectomy	55 (37.4%)	15 (39.5%)	22 (57.9%)	9 (24.3%)	9 (26.5%)
Robot cystectomy	19 (12.9%)	2 (5.3%)	4 (10.5%)	6 (16.2%)	7 (20.6%)
Robot gynaecology	73 (49.7%)	21 (55.2%)	12 (31.6%)	22 (59.5%)	18 (52.9%)
Duration of surgery (min)	138 (76)	121 (64)	129 (65)	143 (72)	162 (98)

Note: Gender and type of operation are given as numbers in each group, age and duration of surgery are given as mean (SD), and BMI (body mass index) and ASA (physical status classification system by the American Society of Anaesthesiologists) are given as medians (min-max).

Abbreviations: AGC, automatic gas control; Et-control, end-tidal gas control; With AGC, Maquet Flow-I with automated gas control device; With Et-control, GE Healthcare Aisys with Et-control device; Without AGC, Maquet Flow-I without an AGC device; Without Et-control, GE Healthcare Aisys without Et-control device.

TABLE 2 Desflurane consumption (mL liquid) after 9, 30 and 60 min

	Desflurane consumption with automatic gas control devices		Desflurane consumption without automatic gas control devices		Estimated difference in desflurane consumption between Flow-I without and with AGC and Aisys without and with Et-control (95% CI)			
	Mean (SD)		Mean (SD)					
Time	Flow-I AGC	Aisys Et-c	Flow-I	Aisys	Flow-I	*P*-value	Aisys	*P*-value
9 min	7.0 (1.1)	5.2 (0.8)	8.2 (1.1)	9.8 (0.8)	1.3 (0.6 to 1.9)	<.001	4.6 (3.9 to 5.2)	<.001
30 min	11.9 (2.1)	9.7 (1.3)	14.3 (1.2)	16.5 (0.8)	2.5 (1.6 to 3.3)	<.001	6.6 (5.7 to 7.5)	<.001
60 min	16.8 (3.4)	15.2 (1.8)	22.1 (1.7)	25.8 (1.1)	5.4 (4.1 to 6.7)	<.001	10.3 (8.9 to 11.6)	<.001

Note: The observed gas consumption is summarized as mean (SD). The estimated differences are results from linear regression analysis adjusted for age and gender, and are given with 95% CI and *P*-values.

Abbreviations: With AGC, Maquet Flow-I with automated gas control device; With Et-c, GE Healthcare Aisys with end-tidal control device; Without AGC, Maquet Flow-I without automated gas control device; Without Et-c, GE Healthcare Aisys without end-tidal control device.

TABLE 3 Estimated difference in desflurane consumption (mL liquid) between machines with automated gas control devices

	Estimated difference in desflurane consumption with automated gas control devices	
	Flow-I AGC vs Aisys Et-c	
Time	Estimate (95% CI)	*P*-value
9 min	1.7 (1.1 to 2.4)	<.001
30 min	1.9 (1.0 to 2.8)	<.001
60 min	1.1 (−0.3 to 2.4)	.215

Note: The estimated differences are results from linear regression analysis adjusted for age and gender, and are given with 95% CI and *P*-values.

Abbreviations: AGC, automatic gas control; Et-c, end-tidal gas control; With AGC, Maquet Flow-I with Automatic gas control device; With Et-c, GE Healthcare Aisys with end tidal control device.

also a time difference without the automatic gas control devices. The mean time to reach a MAC of 0.7 was 12.8 (SD: 10.9) minutes in Flow-I without AGC and 7.5 (SD: 11.9) minutes in Aisys without Et-control ($P = .002$). The end-tidal desflurane concentrations, measured in %, remained stable over time during the study period for both automated gas control devices and in the manual groups (data not shown).

The time to reach a FGF of 0.5 L with the use of an automatic gas control device was 22.0 (SD: 7.3) minutes in the Flow-I with AGC and 4.4 (SD: 2.3) minutes in the Aisys with Et-control ($P < .001$).

4 | DISCUSSION

The results from this study showed a mean reduction in desflurane consumption of 10.3 mL with the use of the Aisys Et-control system compared to conventional low flow anaesthesia after 1 hour of desflurane anaesthesia. For the Flow-I anaesthetic machine, the mean reduction in desflurane consumption between the AGC device and conventional low flow was 5.4 mL after 1 hour.

Singaravelu and Barclay[15] reported that the use of the Aisys Et-control reduced the consumption of both sevoflurane and desflurane. Our results for the Aisys machine agree with these findings. Contrary to our and Singaravelu´s findings, Skalec et al[18] found no difference in sevoflurane consumption between the two groups. Their study design was, however, different from ours as they used a higher FGF of 1.0 L/min, during stable anaesthesia compared to the FGF used in the present study. The FGF used by Skalec et al was the same as the FGF used for conventional manual low flow anaesthesia in the present study. Skalec et al also applied a higher MAC. These differences in study design may explain the different findings.

Our results also showed a difference in the desflurane consumption between Aisys Et-control and Flow-I AGC after 9 and 30 minutes. After 60 minutes there was no longer any evidence of a difference. We find this difference interesting. Reasons for the observed difference in desflurane consumption may be that the time to reach the set values for desflurane with the Aisys Et-control machine is faster than with the Flow-I AGC, which results in a faster reduction of desflurane consumption with the Aisys device compared to Flow-I. An explanation for the lack of difference in desflurane consumption after 60 minutes could be that the default FGF for Flow-I AGC was 0.3 L/min and for Aisys Et-control 0.5 L/min and, therefore, the desflurane consumption for the Aisys Machine with Et-control could be higher than for the Flow-I AGC over time.

We also observed a significant difference in the time needed to reach a MAC of 0.7 between the Aisys Et-control and Flow-I AGC devices as well as in the time to reach a FGF of 0.5 L/min. The estimated difference of 3 minutes in reaching a MAC of 0.7 and 17.6 minutes in reaching a stable FGF may be explained by the fact that the Aisys Et-control and the Flow-I AGC are based on different algorithms.[21,22] In the Flow-I AGC, the volatile anaesthetic agent is injected into the system during inspiration, while in the Aisys Et-control the fresh gas flows continuously through the vaporizer. Based on this, one could anticipate that the desflurane consumption would be lower when using the Flow-I AGC compared to the Aisys Et-control, an assumption different from our observation of lower desflurane consumption in the Aisys Et-control group. One explanation could be the set-up of speed 6 in

our study as Carette et al observed that the volatile anaesthetic consumption in Flow-I AGC is higher for speed 6 compared to speed 2.[17] It is unclear whether the chosen speed for the Flow-I AGC had an impact on our results.

The difference in desflurane consumption is relevant for clinical practice both for the important environmental aspect, as volatile anaesthetic agents released into the environment via the scavenger system have a long half-life in the atmosphere,[23,24] and because of costs. Automatic gas control devices may also contribute to a reduction in the loss of heat and moisture during mechanical ventilation.[13,25,26]

Strengths of the present study are the number of patients studied, and that the study was independent of and not funded by commercial interests. It is also a strength that desflurane delivery was adjusted to a similar MAC to all patients. Thus, differences in desflurane delivery was not influenced from variable need for depth of anaesthesia. Furthermore, one anaesthesiologist (DM) anaesthetised all patients. This ensured that all patients were treated similarly and strictly according to the study protocol. The FGF setting in the manual groups may have inflicted on the differences seen in the time to reach 0.7 MAC between the manual and automatic gas control groups, and may thereby be a study limitation. Other limitations may be the choice of speed 6 on the Flow-I, the low number of registration time points, and that the study was not blinded. The fact that this was a single centre study also represents a possible limitation.

5 | CONCLUSIONS

In summary, our results showed that compared to conventional low flow anaesthesia, the use of automated anaesthetic gas delivery devices reduced desflurane consumption. We also observed an interesting reduction in desflurane consumption with the use of the Aysis Et-control device compared to the Flow-I AGC device after 9 and 30 minutes of anaesthesia. After 60 minutes, this difference was, however, no longer significant. Both devices investigated seemed reliable.

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CONFLICT OF INTEREST

The authors have no conflicts of interests.

ORCID

Dagmar Mostad https://orcid.org/0000-0002-8802-6373

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