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Impact of flow and temperature on non-dyspnoeic dogs' tolerance undergoing high-flow oxygen therapy

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OBJECTIVES: To prospectively describe the impact of gas flow rate and temperature on dog's tolerance of high-flow nasal oxygen therapy during recovery from anaesthesia, hypothesizing that higher flow rates and temperatures will decrease tolerance.

MATERIALS AND METHODS: Twelve non-dyspnoeic client-owned dogs recovering from general anaesthesia were included in this study. After extubation, a nasal cannula was positioned and high-flow nasal oxygen therapy was initiated. Two flow rates (two or four time the theoretical minute ventilation: HF2 and HF4), each of them combined with two temperatures (31 and 37°C: T31 and T37), were randomly applied (four conditions *per dog*). For each condition, cardiovascular and respiratory parameters (heart rate, respiratory rate, systolic arterial blood pressure and pulse oximeter oxygen saturation), sedation score and tolerance score were recorded at initiation (T_0) and after 10 minutes of accommodation (T_{10}).

RESULTS: Sedation scores were not significantly different between the four conditions. Cardiovascular and respiratory parameters were not significantly different between any condition at both T_0 and T_{10} . Tolerance scores were good and not significantly different between any flow rate or temperature (HF2-T31: 4 (2-4), HF4-T31: 4 (2-4), HF2-T37: 4 (2-4), HF4-T37: 4 (1-4)).

CLINICAL SIGNIFICANCE: The gas flow rates and temperatures studied have no impact on tolerance during the recovery period of non-dyspnoeic dogs, and high-flow nasal cannula is well tolerated. Further studies are required to confirm these results in dyspnoeic dogs.

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INTRODUCTION

Oxygen supplementation is often the first line, lifesaving, treatment for hypoxaemic dogs. In veterinary medicine, oxygen therapy is mostly delivered by non-invasive techniques such as flow-by, nasal prongs or oxygen cages. These methods are known as conventional oxygen therapy (COT). They deliver oxygen as a cold dry gas, and can achieve variable fractions of inspired oxygen (FIO₂) ranging from 30 to 70% (Guenther 2018).

Delivery of cold gas could cause patient discomfort at higher rates, desiccation of the nasal mucosa, airway constriction, impairment of the mucociliary function and increased risk of infection (Dunphy *et al.* 2002, Kallstrom 2002, Kopelman & Holbert 2003, Kilgour *et al.* 2004).

Since the early 2000s, an advanced oxygen delivery method, called high-flow nasal oxygen therapy (HFNOT) has received growing attention in human medicine (Guenther 2018). HFNOT uses an air-oxygen blender connected to a flow meter, an active

humidifier and heater, a warmed breathing circuit and a specific bilateral nasal cannula (Pouzot-Nevoret *et al.* 2019). Respiratory support delivered with HFNOT machines is achieved by administration of humidified air/oxygen blends, using high-flow rates up to 60 L/min, adjustable fraction of inspired oxygen (FIO₂) from 21 to 100%, and precise temperature, between 31 and 37°C (Mauri *et al.* 2018). Heated and moistened air inspired through the high-flow nasal cannula (HFNC) improves comfort and compliance of the dyspnoeic human patient (Stefan *et al.* 2018).

HFNOT recommendations settings for paediatric patients are a flow rate from 1 to 2 L/kg/min and a temperature of 34°C (Milési *et al.* 2018, Yurtseven *et al.* 2019). In adult patients, clinicians use flow rates from 50 to 60 L/min, independently of the weight, considering that lung capacities are almost equivalent from one individual to another. Several studies have suggested that an increase in the flow rate may decrease the work of breathing in patients with acute respiratory distress, although this may also impact the patient's comfort (Milési *et al.* 2013, Weiler *et al.* 2017). Recently, the influence of flow rate and temperature on patient comfort using HFNOT was evaluated (Mauri *et al.* 2018). In this study, adult dyspnoeic patients were more comfortable with the temperature set at 31°C than 37°C, with the HFNOT set at both 30 and 60 L/min. However, in the subgroup of patients with FIO₂ ≥ 45%, both lower temperature (31°C) and higher flow rate (60 L/min) led to higher comfort, highlighting the importance of flow rate and temperature on patient's comfort.

In veterinary medicine, feasibility, tolerance and safety of HFNOT have already been proven in healthy and hypoxaemic dogs (Daly *et al.* 2016, 2017, Keir *et al.* 2016, Pouzot-Nevoret *et al.* 2019, Jagodich *et al.* 2020). Its efficacy in increasing the arterial partial pressure of oxygen (PaO₂) compared to COT has also been demonstrated (Daly *et al.* 2016, Keir *et al.* 2016, Jagodich *et al.* 2019, 2020, Pouzot-Nevoret *et al.* 2019). Described flow rates in dogs range from 0.2 to 2.5 L/kg/min (Jagodich *et al.* 2019, 2020; Pouzot-Nevoret *et al.* 2019) or predefined flow rates of 20 to 30 L/min (Daly *et al.* 2017) all derived from human medicine (Kernick & Magarey 2010, Mayfield *et al.* 2014, Mauri *et al.* 2018, Yurtseven *et al.* 2019). However, a flow rate above 2 L/kg/min is not well tolerated in healthy dogs (Jagodich *et al.* 2019). A search on the Pubmed Database with the following keywords: "High flow oxygen" and "dog" was performed on August 19, 2020 and revealed no study reporting the impact of temperature on dogs' tolerance of HFNOT.

The objective of this study was to evaluate the impact of the combination of two different flow rates and temperatures on the tolerance of HFNOT in healthy dogs. We hypothesized that higher flow rates and temperature might reduce tolerance in healthy dogs.

MATERIAL AND METHODS

Study design and inclusion criteria

This study protocol was approved by the VetAgro Sup Ethics committee (number 1849). Written owner informed consent

was obtained during the pre-surgery consultation. Client-owned dogs undergoing general anaesthesia for surgery or diagnostic procedures were enrolled in this prospective blinded randomised crossover study, from January to April 2019. All dogs were deemed healthy before the study on the basis of a complete physical examination.

At the end of the procedure, all dogs were transferred into the emergency and critical care unit (SIAMU, VetAgro Sup) for experimental convenience and were extubated when the swallowing reflex was recovered. In all dogs, type of procedure, duration of anaesthesia (from induction to discontinuation of isoflurane administration) and extubation time were recorded.

The person assessing patient tolerance scores (TS) was blinded to the machine settings which were determined through random order draws and set by another person.

Exclusion criteria

Exclusion criteria at enrolment included dogs below 9.5 kg. This exclusion criterion was due to paediatric manufacture settings of the HFNOT equipment, as paediatric mode of the Airvo™ 2 System is preset to 34°C and thus, did not meet the study model. Other exclusion criteria at enrolment were abnormal findings at physical examination, aggressive or agitated dogs.

High-flow nasal cannula settings

The HFNOT was provided with the Airvo™ 2 System in adult mode (Fisher & Paykel Airvo™ 2 System, Fisher & Paykel Healthcare), using soft silicone bilateral nasal cannula (Optiflow™+ nasal high-flow cannula, Fisher & Paykel Healthcare) as the interface to the patient. Nasal cannulas are available in seven sizes (four paediatrics and three adults). Depending on the dog size and morphology, a cannula was chosen as to occlude a maximum of 50% of the opening of the nares (Fig 1). The adult mode allows adjustable flow rates from 10 to 60 L/min, with a possible increase by steps of 1 L from 10 to 25 L, and by steps of 5 L from 25 to 60 L and with adjustable temperature of 31, 34 or 37°C. The FIO₂ was maintained at 21% as all study dogs were deemed healthy.



FIG 1. High-flow nasal oxygen therapy (Fisher-Paykel Airvo™ 2 System, Fisher & Paykel Healthcare) on a dog with full cardiorespiratory monitoring

Experimental procedure

In order to assure the delivery of the predetermined FIO_2 , the flow rate of HFNOT should be set above the minute ventilation (MV) of the dog [MV = respiratory rate (bpm) × tidal volume (mL/kg)] (Helviz & Einav 2018, Pouzot-Nevoret *et al.* 2019). For each dog, theoretical MV was calculated with a standard respiratory rate (RR) of 20 bpm and a tidal volume of 20 mL/kg considering these dogs were healthy (Testa *et al.* 2014, Helviz & Einav 2018, Milési *et al.* 2018, Jagodich *et al.* 2019). The MV was then multiplied by 2 (High Flow × 2: HF2) or by 4 (HF4), depending on the tested flow rate. When calculated flow rate was under 10 L/min (minimum limit of the Airvo™ 2 System), flow rates of 10 L/min (HF2) and 20 L/min (HF4) were selected. Each dog underwent, in a random order, four 10-minute steps:

- A. Flow rate MV × 2 and temperature 31°C (HF2-T31)
- B. Flow rate MV × 4 and temperature 31°C (HF4-T31)
- C. Flow rate MV × 2 and temperature 37°C (HF2-T37)
- D. Flow rate MV × 4 and temperature 37°C (HF4-T37)

Table 1. High-flow nasal cannula (HFNC) tolerance score (Pouzot-Nevoret *et al.* 2019)

1	The patient does not tolerate the HFNC, is restless, attempts to move and to pull the interface, and needs extra sedation to tolerate the HFNC.
2	The patient tries to remove the interface and is agitated. It is still possible to keep the HFNC on by gently restraining the patient.
3	The patient tolerates the HFNC but looks stressed and afraid; no attempts to remove the interface.
4	The patient is comfortable; no agitation; no attempts to remove the interface.

Transition between each step was done automatically and gradually by the Airvo™ 2 System, and equilibration at each flow rate and temperature couple occurred for 10 minutes before each subsequent recording.

Monitoring

Three-lead electrocardiogram, pulse oximetry (SpO_2) and non-invasive systolic arterial blood pressure (SBP) were monitored during the whole study protocol (Dynascope DS-7100, Fukuda Denshi) (Fig 1).

Data collection

Immediately after extubation, baseline parameters [heart rate (HR), RR, SBP, SpO_2 and temperature] were recorded by the same operator (CH). Then, the nasal cannula attachment was gently tightened behind the neck. Sedation score (SS, Table S1), TS (Table 1) and vital parameters (HR, RR, SBP and SpO_2) were recorded, before the beginning of HFNOT (PreHF). The tubing of the nasal cannula was connected to the Airvo™ 2 System circuit and the first phase of the protocol was started. For each step, flow rate and temperature were determined by randomised drawing and set by a second operator (AF), different from the one assessing TS and SS. For each separate setting, HR, RR, SBP and SpO_2 were recorded at the beginning (T_0) and at the end (T_{10}) of the 10 minutes (Fig 2).

Scoring systems

Dogs were all recovering from general anaesthesia. No additional anaesthetic was used. Given that sedation could influence our results, SS was evaluated at each step of the protocol. The SS was

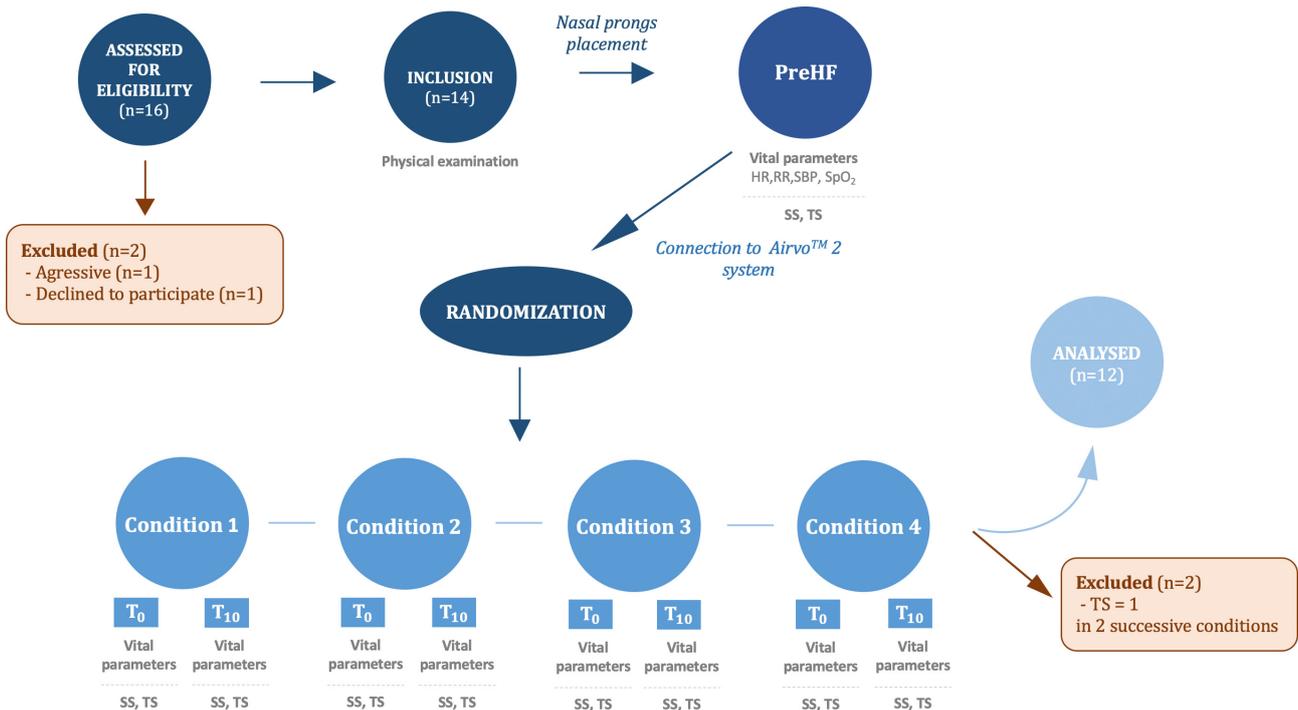


FIG 2. Experimental protocol. Conditions 1 to 4 are applied in a randomised order. HR Heart rate, RR Respiratory rate, SBP Systolic blood pressure, SpO2 Pulse oximetry, SS Sedation score, TS Tolerance score

assessed by an experienced observer (CH) using a visual sedation scale validated by Wagner *et al.* (2017), with a score of 0 indicating no sedation, and 21 indicating deep sedation (Table S1). The SS used is based on the dog's mentation, palpebral reflex, ocular position, jaw and tongue tone, response to clapping, posture and tolerance of lateral recumbency. Sedation was evaluated during PreHF, at the initiation of each setting (T_0) and after the 10 minutes accommodation period (T_{10}) for each setting.

The TS to HFNOT was blindly assessed by the same experienced observer CH, using a simple descriptive scale (Table 1; Pouzot-Nevoret *et al.* 2019). This scale ranges from 1 (least tolerant) to 4 (most tolerant). For the specific aim of the study, if a TS of 1 was recorded, there was an immediate change to the next flow rate-temperature setting. If a TS of 1 was recorded a second time, the dog was excluded from the study.

Outcome

Primary outcome of the study was the evolution of TS under the different HFNOT conditions. Evolution of vital parameters (HR, RR, SBP and SpO₂) under the different HFNOT conditions was the secondary outcome.

Statistical analysis

Before study enrolment, a power analysis was performed to determine minimum sample size to detect a clinically meaningful difference of two points TS between HF2 at a temperature of 31°C and HF4 at a temperature of 37°C. Using an effect size of 0.80 (moderate effect) and significance level (α) of 0.05, the inclusion of four dogs was estimated to find a significant effect.

Statistical analyses were carried out with JMP version 13.1 (SAS Institute) and envelop number pull was used as randomization method. Data were tested for normal distribution with the Shapiro-Wilk test. For all collected data, the mean \pm standard deviation (parametric data) or the median and range (nonparametric data) were calculated. Nonparametric data (duration of anaesthesia, RR and TS) were tested with a Friedman test. Parametric data (HR, SBP, SpO₂ and SS) were compared with a one-way analysis of variance (ANOVA). P values lower than 0.05 were considered statistically significant.

RESULTS

Animals

Sixteen dogs were initially eligible for the protocol (Fig 2). Two of them had to be excluded at enrolment: one because of aggressiveness and one because the owner declined to participate.

Fourteen dogs were therefore enrolled in the study. Two of them had to be excluded because of a TS of 1 in two successive HFNOT settings, associated with a dysphoric anaesthesia recovery. They were very agitated before placement of the cannula and extra sedation would have been necessary to make them tolerate HFNC.

Twelve dogs were in the final study enrolment: five females (two intact and three spayed) and seven males (one intact and six neutered). Breeds included two Mixed Breeds, two Labrador retriev-

ers, one German shepherd dog, one Dogo Argentino, one beagle, one Bernese Mountain Dog, one Chow-Chow, one American Bully, one Brittany and one Braque Français. The mean age and mean bodyweight were 5.8 ± 4.0 years and 29.3 ± 11.8 kg, respectively. Type of procedures included four orthopaedic surgeries (two tibial plate levelling osteotomies, one pelvic limb amputation and one removal of osteosynthesis implant), one ventral slot, one perineal hernia repair, one mass removal, two castrations, one ovariectomy, one pericardiocentesis and one CT scan. Median duration of anaesthesia was 137.5 minutes (40-400 minutes).

Eleven dogs completed all phases of the study. One dog did not tolerate HF4-T37, leading to a change to the next step of the protocol and achievement of three conditions over four. Median flow rate was 24 L/min (10-35 L/min) for the HF2 condition (0.8 L/kg/min), and 47.5 L/min (20-60 L/min) for the HF4 condition (1.6 L/kg/min).

Sedation status

Mean \pm sd SS were 11 ± 6 for PreHF, 6 ± 3 for HF2-T31, 7 ± 4 for HF4-T31, 8 ± 5 for HF2-T37 and 8 ± 4 for HF4-T37 (Fig 3).

Global mean \pm sd SS of the HFNOT conditions was 8 ± 4 and there was no significant difference between any of the HFNOT conditions ($P = 0.711$).

Vital parameters

Median (range) temperature at inclusion was 37.8°C (36.4-38.4°C).

PreHF vital parameters were: HR: 114 ± 38.8 bpm; RR: 40 (16-250) bpm; SBP: 102.8 ± 27.2 mmHg and SpO₂: $95 \pm 3\%$.

There was no effect of flow rate or temperature on vital parameters (HR, RR, SBP and SpO₂) at T_0 and T_{10} (Fig 4 and Table 2).

Effects of flow rate and temperature on tolerance

PreHF TS was 4 (2-4). TS was not significantly different between any of the HFNOT conditions (Table 3).

DISCUSSION

Based on the literature search performed, this is the first veterinary study evaluating the impact of a combination of different flow rates and temperatures on healthy dogs' tolerance of

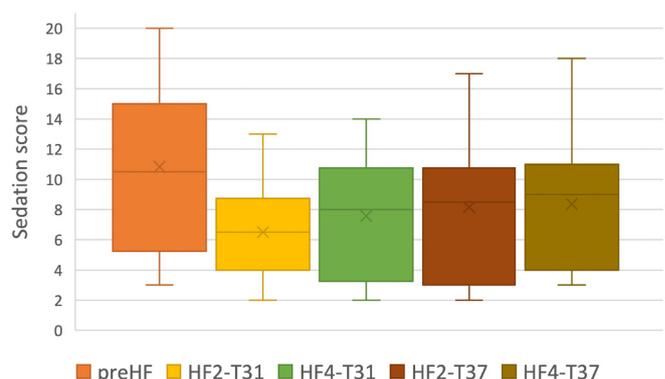


FIG 3. Sedation scores during PreHF and the end (T_{10}) of the four HFNOT conditions

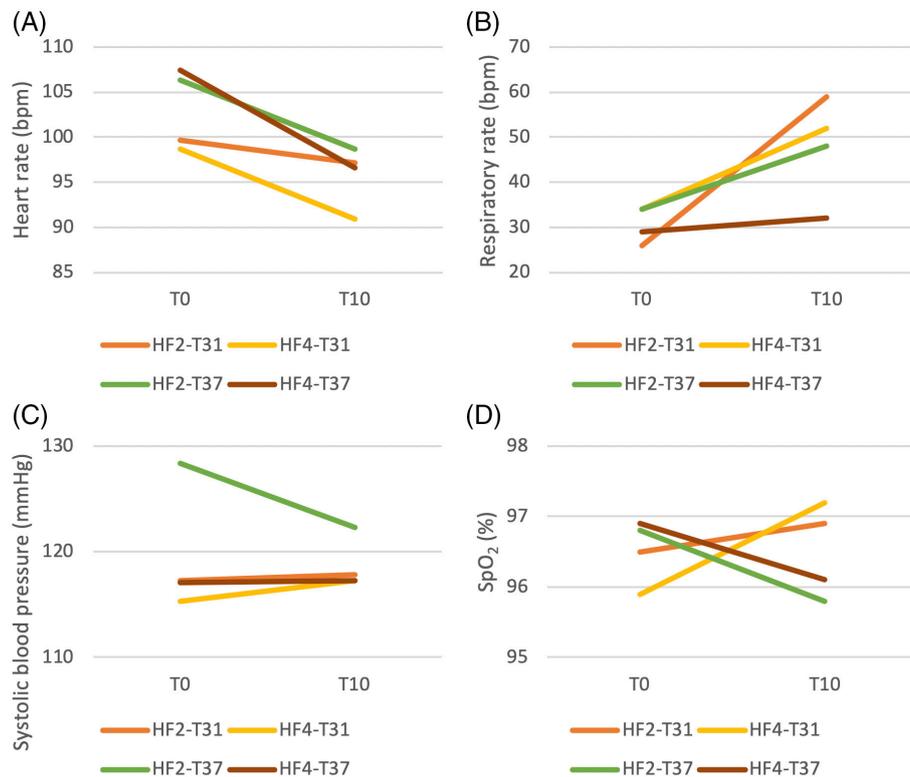


FIG 4. Mean values of heart rate (A), systolic blood pressure (C) and SpO₂ (D) and median values of respiratory rate (B) in the 12 dogs, at the initiation of each condition (T₀) and after 10 minutes of accommodation (T₁₀)

Table 2. Mean ± sd (range) values of heart rate (HR), arterial systolic blood pressure (SBP) and pulse oximeter oxygen saturation (SpO₂) and median (range) values of respiratory rate (RR) in the 12 dogs at T₀ and T₁₀ for each high-flow nasal cannula condition

	HR (bpm)		RR (bpm)		SBP (mmHg)		SpO ₂ (%)	
	T ₀	T ₁₀	T ₀	T ₁₀	T ₀	T ₁₀	T ₀	T ₁₀
HF2-T31	99.7 ± 28.5 (58-147)	97.1 ± 30.1 (60-148)	26 (16-220)	59 (16-260)	117.3 ± 19.6 (85-145)	117.8 ± 22.1 (85-155)	95.5 ± 2.2 (91-99)	95.9 ± 2.3 (92-100)
HF4-T31	98.7 ± 34.2 (45-158)	90.9 ± 27.1 (50-139)	34 (8-260)	52 (16-260)	115.3 ± 28.5 (70-166)	117.3 ± 28.3 (67-166)	95.9 ± 2.2 (91-98)	97.2 ± 2.2 (92-100)
HF2-T37	106.3 ± 35.7 (68-183)	98.7 ± 34.5 (53-167)	34 (16-250)	48 (16-250)	128.4 ± 27.8 (90-196)	122.3 ± 23.7 (86-170)	96.8 ± 2.6 (91-100)	95.8 ± 2.6 (91-98)
HF4-T37	107.4 ± 37.9 (63-169)	96.6 ± 30.4 (53-144)	29 (12-260)	32 (16-260)	117.1 ± 22.9 (75-149)	117.3 ± 21.9 (82-158)	96.9 ± 2.9 (91-100)	96.1 ± 2.6 (90-100)
P values	0.891	0.931	0.981	1.000	0.563	0.948	0.748	0.498

Table 3. Median (range) values of tolerance score (TS) in the 12 dogs and number of dogs for each tolerance score at the end of each high-flow nasal cannula condition (T10)

	HF ₂ -T ₃₁	HF ₄ -T ₃₁	HF ₂ -T ₃₇	HF ₄ -T ₃₇	P value
TS median (range)	4 (2-4)	4 (2-4)	4 (2-4)	4 (1-4)	1.000
TS = 1	0	0	0	1	
TS = 2	2	3	1	1	
TS = 3	2	2	2	2	
TS = 4	8	7	9	8	

HFNOT. The study design was based on Mauri *et al.* (2018)'s clinical trial investigating dyspnoic human patients. Their study revealed improved patient comfort with the administration of lower gas temperatures. This comparison had never

been performed in dogs. In our study, we were not able to show any difference in the dogs' tolerance between HFNOT at 31 or 37°C, by using a tolerance scale. However, all median scores were high, whatever the setting, confirming the good tolerance of this oxygen therapy technique in dogs. Only one dog did not tolerate the first step of the protocol (HF4-T37) but tolerated every other step. A dysphoric waking could have explained this intolerance. Association of highest flow rate and temperature could have also led to this intolerance. Two dogs had to be excluded from the study because of nasal cannula intolerance for two conditions. However, these dogs were highly agitated since the beginning of the recovery period and would have needed extra sedation to tolerate nasal cannula. Sedation is often used in dyspnoic dogs undergoing oxygen therapy. As this study was

conducted during the anaesthetic recovery period and SS was part on the initial assessment, no additional interventions were administered.

Absence of difference between conditions could be related to the choice of the TS. This score has never been validated but was described in the clinical trial of Staffieri *et al.* (2014), in which the objectives were comparable to ours. Between the time our study was designed and the end of the clinical trial, Jagodich *et al.* (2019) published a study using another TS, based on the dog's number of attempts to remove the cannula. This score might be more sensitive as long as they were able to highlight an alteration of tolerance with higher flow rates. This scoring system could be used in future studies. Finally, the dogs in this study were not in respiratory distress and therefore did not need HFNOT. Further studies assessing tolerance of differing gas temperatures in dyspnoeic dogs would be useful.

Given the infancy of HFNOT in veterinary medicine, there is no consensus as to ideal flow rate settings. In human medicine, flow rates of 2–8 L/min (~0.4–3.2 L/kg/min) in neonates and 15–60 L/min (~0.2–1 L/kg/min) in adults are generally used (Kernick & Magarey 2010, Mayfield *et al.* 2014, Mauri *et al.* 2018, Yurtseven *et al.* 2019, Koga *et al.* 2020). The first studies published in dogs used flow rates without considering a dog's bodyweight or RR (20 and 30 L/min, (Daly *et al.* 2017)). In order to avoid recruitment of air or oxygen from the surrounding air and assure the delivery of the predetermined FIO₂, the flow rate should be fixed above the MV of the patient (Helviz & Einav 2018). In our study, we have chosen higher flow rates and attempted to determine a limit to tolerance. The calculated flow rates were equivalent to 0.8 and 1.6 L/kg/min in this study. In the recent study of Jagodich *et al.* (2019), TS appears to be worsened only above 2 L/kg/min. This study, not available at the time of protocol conception, could explain our results showing no significant difference in tolerance for our flow rates range. However, the lower flow rates used in this study were based on previous data showing they could be effective in increasing PaO₂ in dyspnoeic dogs (Pouzot-Nevoiret *et al.* 2019).

This study was conducted in non-dyspnoeic dogs recovering from anaesthesia, so sedation could have influenced TS. Randomization of machine settings order, median SS in the lower range and absence of difference of SSs between all conditions suggest that sedation had a minor influence, at most, on our tolerance evaluation. However, further studies in non-sedated dogs would be required.

The 10-minute period for each setting was chosen based on our clinical experience and previous studies in dyspnoeic dogs. While using HFNOT in dyspnoeic dogs, we noticed that they were generally either compliant from the beginning or never compliant to HFNOT. TSs stayed the same during the 10-minute period, confirming this observation. This duration was decided in the light of the various recent studies. In similar protocols, Mauri *et al.* (2018) in human medicine, and Staffieri *et al.* (2014) in veterinary medicine, used 20-minute steps, whereas Jagodich *et al.* (2019) used 8-minute period of time. However, a longer time frame of assessment could have changed

the tolerance, especially considering the effect of gas temperature on body temperature. Indeed, Gilardi *et al.* (2020) suggested in a preliminary report that median time of rewarming was shorter in hypothermic non-dyspnoeic patients treated with HFNOT, highlighting the influence of heated air administration on body temperature in people. Tolerance evaluation of different temperature in pyrexia or severely hypothermic dogs is indicated.

We experienced some technical constraints with the Airvo™ 2 System, especially the impossibility to use paediatric cannulas in our protocol. Indeed, they can be used only with the paediatric mode in which temperature cannot be changed. These cannulas have a different shape depending on whether they are adult or junior size. We had an excellent general tolerance to HFNOT in our study, using exclusively adult interfaces. Paediatric cannulas are described to be very comfortable, easier to place and with a better accommodation to the facial structure of dogs (Jagodich *et al.* 2019, 2020), suggesting the same results. Moreover, dog's normal rectal temperature is 38.5°C, and the Airvo™ 2 System temperature set up is optimal for human with a normal temperature of 37.5°C. Setting the temperature of the device at 38.5°C could have changed the tolerance. Although we only had access to the Airvo™ 2 System, other devices are available on the market. For example, Precision Flow® Plus system (Vapotherm® Precision Flow® Plus, Vapotherm® inc) can be adjusted by 1-degree intervals, at all flow rates, independently of the cannula size (paediatric or adult). Further studies would be interesting to determine if a precise regulation of the gas temperature influence dog's tolerance.

There are some limitations in this current study. First, the protocol included only dogs with no respiratory issues, recovering from general anaesthesia. Further studies are required to evaluate the degree of HFNOT tolerance in fully conscious dogs and for longer periods. Moreover, the efficacy of this system in different pathological conditions should be supported by further studies. Second, the impact of flow rates and temperatures on PaO₂ has not been evaluated in this protocol. Daly *et al.* (2017) showed that HFNOT significantly improved PaO₂ versus COT but there was no significant difference in PaO₂ between rates of 20 and 30 L/min. Jagodich *et al.* (2019) highlighted that HFNOT significantly improved PaO₂ compared to baseline and PaO₂ was significantly higher at rate of 1 L/kg/min or more, compared to 0.4 L/kg/min. The potential impact of temperature on oxygenation has never been investigated and further studies will be necessary. Third, clinical complications associated with HFNOT, like gastric dilation, have not been evaluated in our study. However, none of our 12 dogs showed any clinical abdominal distension or discomfort. Finally, non-cooperative or aggressive dogs could not be included in the study because frequent head manipulations were necessary which could represent a bias.

In conclusion, this study is the first in veterinary medicine to evaluate the combined impact of flow rate and temperature on non-dyspnoeic dogs' tolerance of HFNOT and shows no significant difference between 31 and 37°C. It also confirms the high degree of tolerance of HFNOT in healthy dogs of varied body sizes and gives practical information on its use in this species. No clear recommendation for flow rate and temperature settings

could be determined based on our results, and user should combine available data in veterinary literature with evaluation of tolerance and efficacy on their patients to guide settings of non-invasive respiratory support by HFNOT.

Conflict of interest

No conflicts of interest have been declared.

References

- Daly, J., Guenther, C. & Haggerty, J. (2016) Impact of high flow nasal cannula in dogs with hypoxemia. Proceedings of the International Veterinary Emergency and Critical Care Society, September 7 to 11, Grapevine, USA. p S4
- Daly, J. L., Guenther, C. L., Haggerty, J. M., et al. (2017) Evaluation of oxygen administration with a high-flow nasal cannula to clinically normal dogs. *American Journal of Veterinary Research* **78**, 624-630
- Dunphy, E. D., Mann, F. A., Dodam, J. R., et al. (2002) Comparison of unilateral versus bilateral nasal catheters for oxygen administration in dogs. *Journal of Veterinary Emergency and Critical Care* **12**, 245-251
- Gilardi, E., Petrucci, M., Sabia, L., et al. (2020) High-flow nasal cannula for body rewarming in hypothermia. *Critical Care* **24**, 122
- Guenther, C. (2018) Oxygen therapy. In: Textbook of Small Animal Emergency Medicine. J. Wiley & Sons Inc, Hoboken, NJ, USA. pp 1177-1182
- Helviz, Y. & Einav, S. (2018) A systematic review of the high-flow nasal cannula for adult patients. *Critical Care* **22**, 71
- Jagodich, T. A., Bersenas, A. M. E., Bateman, S. W., et al. (2019) Comparison of high flow nasal cannula oxygen administration to traditional nasal cannula oxygen therapy in healthy dogs. *Journal of Veterinary Emergency and Critical Care* **29**, 246-255
- Jagodich, T. A., Bersenas, A. M. E., Bateman, S. W., et al. (2020) Preliminary evaluation of the use of high-flow nasal cannula oxygen therapy during recovery from general anesthesia in dogs with obstructive upper airway breathing. *Journal of Veterinary Emergency and Critical Care* **30**(4), 487-492
- Kallstrom, T. J. (2002) AARC clinical practice guideline: oxygen therapy for adults in the acute care facility – 2002 revision & update. *Respiratory Care* **47**, 717-720
- Keir, I., Daly, J., Haggerty, J., et al. (2016) Retrospective evaluation of the effect of high flow oxygen therapy delivered by nasal cannula on PaO₂ in dogs with moderate-to-severe hypoxemia. *Journal of Veterinary Emergency and Critical Care* **26**, 598-602
- Kernick, J. & Magarey, J. (2010) What is the evidence for the use of high flow nasal cannula oxygen in adult patients admitted to critical care units? A systematic review. *Australian Critical Care* **23**, 53-70
- Kilgour, E., Rankin, N., Ryan, S., et al. (2004) Mucociliary function deteriorates in the clinical range of inspired air temperature and humidity. *Intensive Care Medicine* **30**, 1491-1494
- Koga, Y., Kaneda, K., Fujii, N., et al. (2020) Comparison of high-flow nasal cannula oxygen therapy and non-invasive ventilation as first-line therapy in respiratory failure: a multicenter retrospective study. *Acute Medicine & Surgery* **7**, e461
- Kopelman, A. E. & Holbert, D. (2003) Use of oxygen cannulas in extremely low birthweight infants is associated with mucosal trauma and bleeding, and possibly with coagulase-negative staphylococcal sepsis. *Journal of Perinatology* **23**, 94-97
- Mauri, T., Galazzi, A., Binda, F., et al. (2018) Impact of flow and temperature on patient comfort during respiratory support by high-flow nasal cannula. *Critical Care* **22**, 120
- Mayfield, S., Jauncey-Cooke, J., Hough, J. L., et al. (2014) High-flow nasal cannula therapy for respiratory support in children. *The Cochrane Database of Systematic Reviews* **3**(mars), 1-30. <https://doi.org/10.1002/14651858.CD009850.pub2>
- Milési, C., Baleine, J., Matecki, S., et al. (2013) Is treatment with a high flow nasal cannula effective in acute viral bronchiolitis? A physiologic study. *Intensive Care Medicine* **39**, 1088-1094
- Milési, C., Pierre, A. F., Deho, A., et al. (2018) A multicenter randomized controlled trial of a 3-L/kg/min versus 2-L/kg/min high-flow nasal cannula flow rate in young infants with severe viral bronchiolitis (TRAMONTANE 2). *Intensive Care Medicine* **44**, 1870-1878
- Pouzot-Nevoret, C., Hocine, L., Nègre, J., et al. (2019) Prospective pilot study for evaluation of high-flow oxygen therapy in dyspnoeic dogs: the HOT-DOG study. *The Journal of Small Animal Practice* **60**, 656-662
- Staffieri, F., Crovace, A., De Monte, V., et al. (2014) Noninvasive continuous positive airway pressure delivered using a pediatric helmet in dogs recovering from general anesthesia. *Journal of Veterinary Emergency and Critical Care* **24**, 578-585
- Stefan, M. S., Bogdan Tiru, P. E., Friderici, J., et al. (2018) High flow nasal oxygen therapy utilization: 7-year experience at a community teaching hospital. *Hospital Practice* **46**, 73-76
- Testa, G., Iodice, F., Ricci, Z., et al. (2014) Comparative evaluation of high-flow nasal cannula and conventional oxygen therapy in paediatric cardiac surgical patients: a randomized controlled trial. *Interactive Cardiovascular and Thoracic Surgery* **19**, 456-461
- Wagner, M. C., Hecker, K. G. & Pang, D. S. J. (2017) Sedation levels in dogs: a validation study. *BMC Veterinary Research* **13**, 110
- Weiler, T., Kamerkar, A., Hotz, P. A., et al. (2017) The relationship between high flow nasal cannula flow rate and effort of breathing in children. *The Journal of Pediatrics* **189**, 66-71
- Yurtseven, A., Turan, C., Erseven, E., et al. (2019) Comparison of heated humidified high-flow nasal cannula flow rates (1-L·kg·min⁻¹ vs 2-L·kg·min⁻¹) in the management of acute bronchiolitis. *Pediatric Pulmonology* **54**, 894-900

Supporting Information

The following supporting information is available for this article:

Table S1: Sedation score (Wagner et al. 2017).