

# Effect of Body Weight Loss on Cardiopulmonary Function Assessed by 6-Minute Walk Test and Arterial Blood Gas Analysis in Obese Dogs

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**Background:** Few studies show the detrimental effect of canine obesity on cardiopulmonary function (CPF). The 6-Minute Walk Test (6MWT) is a noninvasive exercise test easy to perform in clinical settings.

**Objective:** The aim of this study was to investigate the effect of obesity and body weight loss (BWL) on CPF assessed by the 6MWT and arterial blood gas analysis.

**Animals:** Six experimental Beagles and 9 privately owned obese dogs were enrolled in a diet-induced BWL program.

**Methods:** Arterial blood gas analysis and 6MWT were repeated in obese subjects (BCS 8-9/9), in the middle of BWL (overweight, BCS 6-7/9), and in lean dogs (BCS 5/9). Heart rate (HRp) and oxygen saturation (SpO<sub>2</sub>) were measured by pulse oximetry before the 6MWT, at midtest, and during a 5-minute recovery period.

**Results:** Twelve dogs completed the BWL program (initial BW,  $27.3 \pm 2.9$  kg; final BW,  $20.85 \pm 2.9$  kg;  $\text{lsmeans} \pm \text{SE}$ ,  $P \leq .001$ ). BWL caused a significant increase in 6MWT walked distance (WD; obese:  $509 \pm 35$  m; overweight:  $575 \pm 36$  m; lean:  $589 \pm 36$  m;  $P \leq .05$ ). Resting arterial blood gas results were not influenced by BWL. Including all time points, obese dogs showed higher HRp and lower SpO<sub>2</sub> compared to overweight and lean dogs. SpO<sub>2</sub> at the end of the walk was significantly lower in obese dogs.

**Conclusion and Clinical Importance:** Obesity negatively affects 6MWT performances in dogs. The 6MWT may be used to demonstrate the efficacy of BWL to improve CPF and quality of life in obese dogs. Although BWL induced significant improvement of cardiopulmonary parameters before ideal BW, WD improved until the end of the BWL program.

**Key words:** Canine; Obesity; Pulmonary function testing.

Obesity is a common nutritional problem in canine medicine, occurring in 20–40% of dogs in the general population.<sup>1</sup> Consequences of obesity on health have been well documented in dogs and several studies have objectively assessed the effects of obesity on several body systems such as in endocrine<sup>2</sup> or cardiovascular.<sup>3</sup> Obesity also may subjectively worsen clinical signs in several respiratory disorders, such as brachycephalic airway obstruction syndrome<sup>4</sup> or tracheal collapse.<sup>5</sup> However, scientific evidence and proper characterization of the effect of obesity on the respiratory system are scarce<sup>6,7</sup> in the veterinary literature.

Development of pulmonary function testing in human medicine<sup>8</sup> helped to better describe and understand the effects of obesity on lung function.<sup>9,10</sup> Arterial blood gas analysis is an important noninvasive pulmonary function test extensively used in human

## Abbreviations:

|                     |                                                                       |
|---------------------|-----------------------------------------------------------------------|
| 6MWT                | 6-minute walk test                                                    |
| BCS                 | body condition score                                                  |
| BE                  | base excess                                                           |
| BWL                 | body weight loss                                                      |
| CPF                 | cardiopulmonary function                                              |
| DM                  | dry matter                                                            |
| HCO <sub>3</sub>    | bicarbonate                                                           |
| HRc                 | heart rate based on femoral pulse evaluation                          |
| HRp                 | heart rate based on pulse oximetry                                    |
| mME                 | measured metabolizable energy                                         |
| paCO <sub>2</sub>   | arterial partial pressure of carbon dioxide                           |
| paO <sub>2</sub>    | arterial partial pressure of oxygen                                   |
| PAO <sub>2</sub>    | calculated alveolar partial pressure of oxygen                        |
| AaDO <sub>2</sub>   | alveolar-arterial oxygen tension difference                           |
| pCO <sub>2</sub>    | partial pressure of carbon dioxide                                    |
| pO <sub>2</sub>     | partial pressure of oxygen                                            |
| RR                  | respiratory rate                                                      |
| SaO <sub>2</sub>    | arterial blood oxygen saturation based on arterial blood gas analysis |
| SpO <sub>2</sub>    | blood oxygen saturation based on pulse oximetry                       |
| TV                  | tidal volume                                                          |
| VO <sub>2</sub> max | maximal oxygen consumption                                            |
| WD                  | walked distance during a 6MWT                                         |

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pulmonology. Morbidly obese humans have unfavorable arterial blood gas results at rest<sup>9,11</sup> and significant improvement after body weight loss (BWL).<sup>12</sup>

To our knowledge, only 2 experimental studies described the effect of obesity on basal lung function parameters in dogs, both using plethysmography.<sup>6,7</sup> However, there are no published data about the effect of canine obesity and subsequent BWL on arterial blood gas parameters.

Walking tests have been used in human medicine since the 1960s.<sup>13</sup> The 6-Minute Walk Test (6MWT) is performed by measuring the distance an individual can walk comfortably in 6 min.<sup>13</sup> This test directly measures patient's ability to undertake daily activities instead of evaluating exercise capacity. Therefore, it is often used for patients with chronic cardiopulmonary conditions to evaluate the patient's quality of life.<sup>14</sup>

Recently, the 6MWT has been evaluated in dogs providing a reproducible test<sup>a</sup> that is easy to perform in clinical settings and able to discriminate between healthy dogs and dogs with pulmonary disease.<sup>15</sup>

In human medicine, cardiopulmonary parameters monitored during a walking test or during the recovery period after exercise have been used to provide additional clinical information in obese subjects.<sup>10,16</sup> To our knowledge, monitoring of heart rate and oxygen saturation during and after exercise has not been investigated in obese dogs and might help to better understand and characterize CPF changes associated with canine obesity and subsequent BWL.

Many of the studies conducted on obese dogs have used either experimentally induced obese animals,<sup>17</sup> fed high-fat diets to rapidly increase their body weight (BW), or naturally obese privately owned dogs affected by chronic obesity.<sup>18,19</sup> To our knowledge, there is no study investigating the CPF differences between chronic naturally obese subjects and experimentally obese dogs. CPF deterioration is well established in obese human patients,<sup>9,10</sup> but there is no clear information available about the time necessary for CPF deterioration to occur in these patients. Obesity in humans is a progressive chronic condition and some complications may develop gradually. Therefore, CPF differences may exist between a group of dogs artificially and recently made obese and chronic naturally obese patients.

The aim of this study was to investigate the effect of obesity and BWL on pulmonary function assessed by 6MWT and arterial blood gas analysis. Our hypotheses were that (1) obese dogs would have deteriorated pulmonary function, detectable by arterial blood gas analysis and 6MWT performances, (2) BWL would be associated with significant improvement of pulmonary function detectable by both arterial blood gas analysis and 6MWT performances, and (3) dogs with natural chronic obesity would have a different degree of pulmonary function deterioration and would show a different pattern of improvement after BWL compared to dogs with experimentally induced obesity.

## Materials and Methods

### *Animals*

Two different groups of dogs were considered in this study: 1 group of dogs with experimentally induced obesity and 1 group of dogs with chronic natural obesity.

The first group included 6 healthy Beagles. Dogs were weighed using an electronic weight scale<sup>b</sup> and body condition score (BCS) was assessed on each of them by a 9-point scale system, as previously described.<sup>20</sup> Before being included in the protocol, all dogs

underwent a fattening dietary regimen in order to reach a BCS  $\geq 8$ . To gain weight, the animals were fed a high-energy commercial extruded diet<sup>c</sup> once daily that was formulated to contain 30.5% DM crude protein, 27% DM crude fat, 2.1% DM crude fiber, and 17.7 kJ/g as fed of measured metabolizable energy (mME). The amount of food offered was individually calculated to reach twice the maintenance requirements, estimated as  $130 \text{ kcal} \times (\text{BW})^{0.75}$ , according to the recommendations of the National Research Council (2006).

Once obese, all dogs were clinically evaluated and no clinical sign could be detected. Hematology and biochemical analysis were within normal limits.

The Ethics Committee for Animal Well Being of the University of Liège approved the experimental protocol (No. 921).

In parallel, 9 client-owned adult dogs with chronic gross obesity (BCS  $\geq 8$ ) but otherwise healthy also were recruited.

Complementary testing including hematology and serum biochemistry, endocrinology testing, diagnostic imaging or ophthalmological examination were performed at the clinicians' discretion when judged necessary after thorough clinical examination. Subjects with any clinical relevant problem that could interfere with the 6MWT performance (eg, orthopedic problems, vision impairment, fever, cardiopulmonary diseases) or any abnormal testing results at any time during the protocol were excluded from the study. Owners were asked to sign an informed consent form before their pet could take part in the study.

The protocol was organized so that no testing would be performed during the summer (between June and September) to avoid high temperature, which could have confounded our results. Room temperature and humidity were considered very stable in the building for the rest of the year.

### *Weight Loss Program*

All obese dogs included in the study were subjected to a diet-induced BWL program aiming to achieve a BCS of 5/9. A low-energy-dense commercial extruded diet was used<sup>d</sup> (34.6% DM crude protein, 9% DM crude fat, 13.1% DM crude fiber, 12.6 kJ/g as fed of mME) and the amount of food was individually calculated to allow a weekly BW loss of 2% of the initial BW. Weekly BCS and BW evaluations were planned for each dog using the same scale,<sup>a</sup> and the amount of food was adjusted as needed.

### *Arterial Blood Gas Analysis*

Arterial blood gases were evaluated before each 6MWT in all dogs when they were obese (BCS  $\geq 8$ ), in the middle of their BWL program (BCS 6–7), and once they had reached their ideal BW (BCS 5).

Blood was taken from the dorsal metatarsal artery and collected in lyophilized lithium heparin syringes<sup>e</sup> using a 22-gauge needle. Dogs were positioned in lateral recumbency to allow easy access to the artery. Because most dogs were panting and some became excessively stressed, the procedure was canceled if not successful within 10 min. Air bubbles were removed and the syringes were capped as quickly as possible to minimize air contact and before being transported to the automated blood gas analyzer.<sup>f</sup> All samples were analyzed within 2 min after blood collection.

Partial pressure of oxygen ( $\text{paO}_2$ ), partial pressure of carbon dioxide ( $\text{paCO}_2$ ), and blood pH were measured and corrected for current body temperature. Alveolar oxygen partial pressure ( $\text{PAO}_2$ ), alveolar-arterial oxygen tension difference ( $\text{AaDO}_2$ ), bicarbonate ( $\text{HCO}_3$ ), base excess (BE) in blood, and arterial oxygen saturation ( $\text{SaO}_2$ ) were automatically calculated by the blood

gas analyzer<sup>f</sup> based on standard National Committee for Clinical Laboratory Standards (NCCLS) equations.

### **Six-Minute Walk Test**

This procedure was performed 3 times for each dog: in the 12 obese dogs (BCS  $\geq 8$ ), in the middle of their BWL program (BCS 6–7), and once they had reached their ideal BW (BCS 5).

Before starting the 6MWT, basal clinical heart rate (HRc) and respiratory rate (RR) were obtained by palpation of the femoral artery and thoracic inspection, respectively.

In addition, a handheld pulse oximeter<sup>g</sup> was used to make 3 successive measurements of heart rate (HRp) and oxygen saturation (SpO<sub>2</sub>) allowing calculation of basal mean values before the walk (T0). The pulse oximeter probe was placed on nonpigmented areas of the buccal mucosa when possible. When it was too pigmented, probe was placed on vaginal or preputial mucosa. In order to be valid, pulse oximeter values had to be recorded within 30 s. If not, the time point was associated with a pulse oximetry failure.

After a few minutes of acclimatization, dogs were allowed to walk at their own pace for 6 min, along an unobstructed 53 m long L-shaped hallway. Dogs were walked when there were no other persons or animals around that could represent a potential distraction.

After 3 min (T3), dogs were stopped to allow one of the operators to record pulse oximetry midtest values for HRp and SpO<sub>2</sub>. Time necessary to read a result (2–30 s) was added to the 6MWT. Dogs were stopped again once the walking time allowed to each patient was over. HRp and SpO<sub>2</sub> were measured immediately at the end of the walk (T6) and 1, 2, 3, and 5 min after the end of the test (T7, T8, T9, and T11).

The total walked distance was measured and reported in meters.

### **Statistical Analysis**

Parameters related to the 6MWT (WD, HRp, SpO<sub>2</sub>) and to arterial blood analysis (pH, PaO<sub>2</sub>, PaCO<sub>2</sub>, PAO<sub>2</sub>, AaDO<sub>2</sub>, HCO<sub>3</sub>, BE, SaO<sub>2</sub>) were assessed as normally distributed (Shapiro–Wilk test  $>0.90$ , PROC UNIVARIATE of SAS, 2006) and subsequently analyzed using a repeated mixed linear model (PROC MIXED of SAS, 2006) to detect the fixed effect of the repeated time effect (corresponding to the weight loss effect: obesity versus overweight versus lean condition), the effect of type of obesity (natural chronic obesity versus experimentally induced obesity), and the effect of their interaction. The effect of dog was considered random.

HRp and SpO<sub>2</sub> were analyzed by a repeated mixed linear model (PROC MIXED of SAS, 2006) to assess the effect of type of obesity, time (corresponding to the weight loss effect: obesity versus overweight versus lean condition), time points (before the 6MWT [T0], in the middle of the test [T3] and at 0, 1, 2, 3, and 5 min [T6, T7, T8, T9, and T11] posttest) and the interactions between type of obesity and time points and between time and time points. The effect of dog was considered random.

For both analyses, least squares means (LSMEANS) were calculated and standard error (SE) was provided as uncertainty index of the estimation. *P* values for the multiple comparisons of the interaction effects were adjusted using the Bonferroni method and *P*  $< .05$  were considered significant.

## **Results**

### **Animals**

Twelve dogs were included in the study including 6 experimental Beagles and 6 of the 9 client-owned dogs

initially recruited, which completed the BWL protocol. The 6 Beagles were all intact females between 5 and 11 years old. As for client-owned dogs, the final group was composed of 3 intact females, 1 intact male, and 2 castrated males, between 6 and 10 years old. Different breeds were represented in this group including 1 Cocker Spaniel, 1 Cavalier King Charles Spaniel, 1 Labrador Retriever, 1 Weimaraner, 1 Border Collie cross-breed and 1 Rottweiler cross-breed.

### **Type of Obesity**

When type of obesity was considered in the statistical analysis, there was no significant difference for any of the parameters analyzed between experimentally induced obese dogs and naturally obese dogs.

### **Weight Loss Program**

The 6 experimental Beagles included in our study gained weight and reached the target obese condition in 16 weeks before successfully completing their BWL program and reaching the targeted ideal BW (BCS=5/9) in a mean time of 22 weeks. Six of 9 enrolled privately owned obese dogs also completed the BWL program but needed a mean time of 32 weeks. The remaining 3 client-owned dogs dropped out because of a lack of owner compliance. The mean BW decreased progressively and significantly (*P*  $< .001$ ) from  $27.3 \pm 2.86$  kg (LSMEANS  $\pm$  SE) in obese dogs to  $23.8 \pm 2.86$  kg in overweight animals and finally  $20.8 \pm 2.86$  kg in the lean dogs group.

### **Resting Clinical Examination in All Obese Dogs**

Mean resting RR value was  $49 \pm 4$  rpm. Five dogs were already panting at rest before the walk and RR was not measured in these dogs. Mean resting HRc value was  $132 \pm 7$  bpm. HRc was not recorded in 1 obese dog. (Table 1)

### **Arterial Blood Gas Analysis in All Obese Dogs**

In 2 obese patients, arterial blood gas values were not available. For the remaining obese dogs, mean values for PaO<sub>2</sub>, PaCO<sub>2</sub>, SaO<sub>2</sub>, HCO<sub>3</sub>, and AaDO<sub>2</sub> are shown in Table 1. Mean values for pH, BE, and PAO<sub>2</sub> (data not shown) were within the normal reference range.

### **6-MWT Performances in All Obese Dogs**

Obese dogs walked a mean distance of  $509 \pm 35$  m (LSMEANS  $\pm$  SE) during 6 min. None of the patients experienced any complication or syncope during or after exercise. Progressive and moderate exercise intolerance was subjectively reported in all obese dogs during the last half of the required exercise. All obese dogs were panting at the end of the walk and during the 5 min after exercise.

**Table 1.** Effect of body weight loss on resting respiratory rate (RR pretest) and heart rate (HRc pretest), on resting arterial blood gas parameters, and on 6-Minute Walk Test (6MWT) walked distance (WD).

|            | Parameter                 | Mean $\pm$ SD               | Range        | n  |
|------------|---------------------------|-----------------------------|--------------|----|
| Obese      | RR pretest (rpm)          | 45 $\pm$ 12 <sup>a</sup>    | 28–64        | 7  |
|            | HRc pretest (bpm)         | 132 $\pm$ 20 <sup>a</sup>   | 100–164      | 11 |
|            | PaO <sub>2</sub> (mmHg)   | 95.00 $\pm$ 16.21           | 70.00–127.00 | 10 |
|            | PaCO <sub>2</sub> (mmHg)  | 37.23 $\pm$ 6.06            | 23.80–43.90  | 10 |
|            | SaO <sub>2</sub> (%)      | 90 $\pm$ 4                  | 84–95        | 10 |
|            | HCO <sub>3</sub> (mmol/L) | 22.19 $\pm$ 3.38            | 15.00–26.20  | 10 |
|            | AaDO <sub>2</sub> (mmHg)  | 12.48 $\pm$ 9.53            | 0.00–30.50   | 10 |
|            | WD (m)                    | 509 $\pm$ 118 <sup>a</sup>  | 238–650      | 12 |
| Overweight | RR pretest (rpm)          | 39 $\pm$ 12 <sup>ab</sup>   | 20–60        | 9  |
|            | HRc pretest (bpm)         | 105 $\pm$ 26 <sup>b</sup>   | 60–144       | 11 |
|            | PaO <sub>2</sub> (mmHg)   | 89.26 $\pm$ 17.87           | 57.60–117.70 | 11 |
|            | PaCO <sub>2</sub> (mmHg)  | 38.12 $\pm$ 4.73            | 29.80–44.90  | 11 |
|            | SaO <sub>2</sub> (%)      | 92 $\pm$ 4                  | 83–95        | 11 |
|            | HCO <sub>3</sub> (mmol/L) | 21.90 $\pm$ 2.23            | 17.00–26.40  | 11 |
|            | AaDO <sub>2</sub> (mmHg)  | 21.88 $\pm$ 19.97           | 0.00–58.20   | 11 |
|            | WD (m)                    | 571 $\pm$ 132 <sup>ab</sup> | 344–815      | 12 |
| Lean       | RR pretest (rpm)          | 33 $\pm$ 6 <sup>b</sup>     | 24–40        | 9  |
|            | HRc pretest (bpm)         | 106 $\pm$ 22 <sup>ab</sup>  | 78–144       | 12 |
|            | PaO <sub>2</sub> (mmHg)   | 88.71 $\pm$ 14.61           | 62.30–109.60 | 12 |
|            | PaCO <sub>2</sub> (mmHg)  | 35.49 $\pm$ 5.12            | 21.80–40.00  | 12 |
|            | SaO <sub>2</sub> (%)      | 92.36 $\pm$ 2.98            | 88.00–96.40  | 12 |
|            | HCO <sub>3</sub> (mmol/L) | 21.38 $\pm$ 2.52            | 15.20–24.70  | 12 |
|            | AaDO <sub>2</sub> (mmHg)  | 21.55 $\pm$ 17.08           | 0.00–53.00   | 12 |
|            | WD (m)                    | 611 $\pm$ 88 <sup>b</sup>   | 452–738      | 12 |

Data are shown as mean values  $\pm$  SD, n = number of values available.

Different letters<sup>a,b</sup> mean statistically significant different values;  $P < .05$ .

Pulse oximeter mean values for HRp and SpO<sub>2</sub> before the test, at midtest, and during 5 min after the end of the walk in obese dogs are presented in Figure 1 (HRp) and Figure 2 (SpO<sub>2</sub>). Results showed a nonsignificant HRp increase during the exercise before a progressive decrease during the recovery period. SpO<sub>2</sub> values showed an opposite trend, decreasing during the exercise and increasing toward resting values after the end of the exercise. Pulse oximetry failure rate was variable in the obese dogs. For example, values were not obtained in only 2 of 12 dogs at T0, but as many as 5 of 12 experienced reading failures at T3.

### Weight Loss Effect on Resting Clinical Examination

Mean pretest RR decreased progressively as subjects lost weight. RR in lean subjects was significantly lower compared to RR measured in the obese group (Table 1). Fewer dogs (3 versus 5) were panting at rest in both overweight and lean subjects compared to obese dogs.

Mean pretest HRc was significantly higher in obese dogs compared to overweight dogs. However, no difference was detected between the obese dogs and the lean dogs. HRc was not available in 1 overweight dog (Table 1).

### Weight Loss Effect on Arterial Blood Gas Analysis

An arterial blood sample was not obtained in 2 overweight dogs. BWL had no significant effect on any of the measured arterial blood gas parameters. Mean values for PaO<sub>2</sub>, PaCO<sub>2</sub>, SaO<sub>2</sub>, HCO<sub>3</sub>, and AaDO<sub>2</sub> in the 3 groups are shown in Table 1.

### Weight Loss Effect on 6-MWT Performances

Body weight loss caused a progressive increase in WD with a significantly longer WD in lean subjects compared to obese dogs (Table 1). Subjective improvement in the demeanor of all dogs during the test was also noted. There was no more exercise intolerance reported in any of the lean dogs. However, all overweight and lean patients still were panting at the end of the exercise and during the 5-min recovery period.

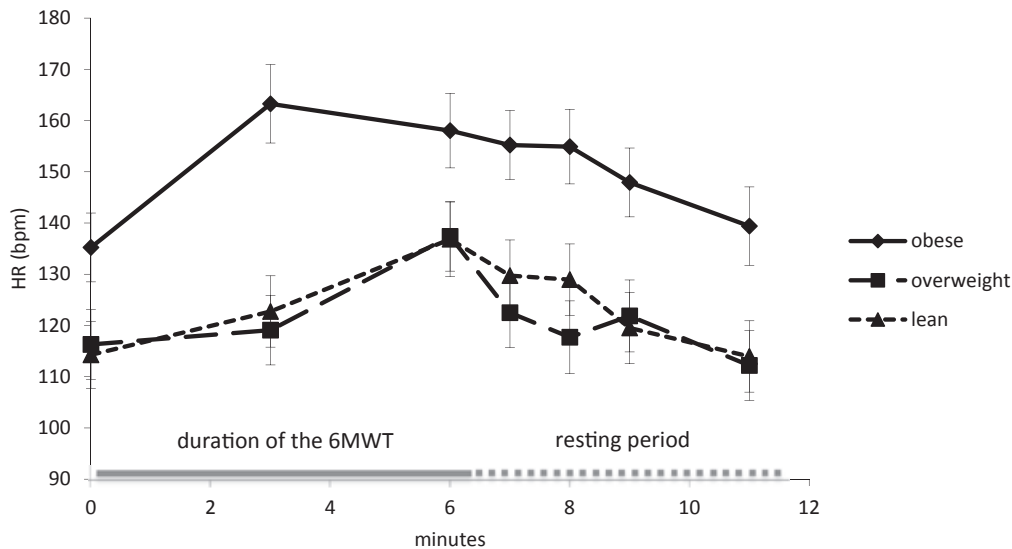
The impact of BWL on HRp and SpO<sub>2</sub> during and after exercise is presented in Figure 1 (HRp) and Figure 2 (SpO<sub>2</sub>). Including all time points, obese dogs showed significantly higher mean HRp values and significantly lower mean SpO<sub>2</sub> values than overweight and lean dogs (HRp, bpm: obese, 150.6  $\pm$  4.5; overweight, 121  $\pm$  4.5; lean, 123.7  $\pm$  4.4, means  $\pm$  SE,  $P < .001$ ; SpO<sub>2</sub>, %: obese, 87.0  $\pm$  0.88; overweight, 91.3  $\pm$  0.90; lean, 91.8  $\pm$  0.84, means  $\pm$  SE,  $P < .001$ ).

The trend described in obese dogs for HRp (Fig 1) and SpO<sub>2</sub> (Fig 2) during and after exercise still was visible in overweight and lean dogs. However, differences between time points were more modest in these groups for both parameters. Statistical analysis failed to show a significant effect of BWL on HRp among the different time points (Fig 1). SpO<sub>2</sub> in obese dogs was significantly lower at the end of the walk (T6) compared to overweight and lean patients (Fig 2).

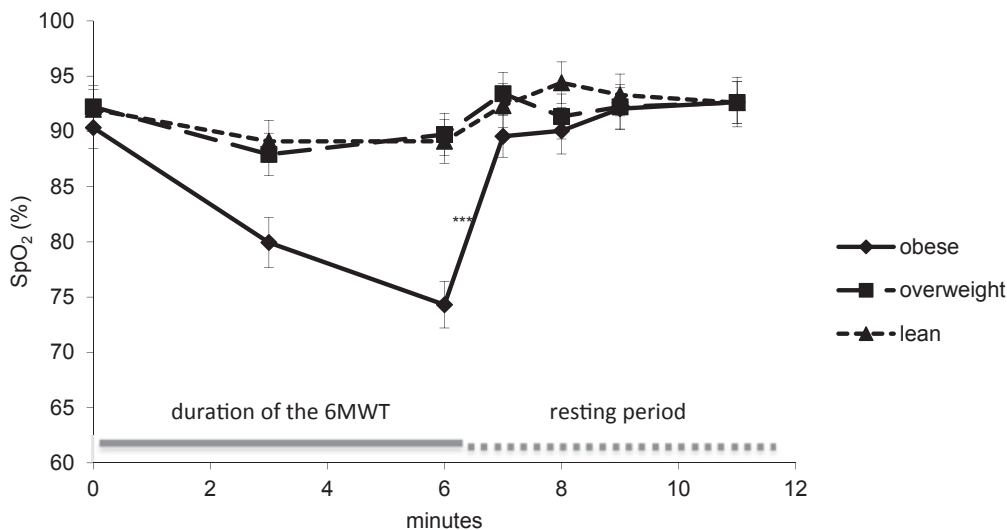
Pulse oximetry failure rate was still very variable in overweight and lean patients. Values were not obtained in 1 of the 12 lean dogs at T0 and as many as 3 reading failures were reported at several time points posttest in overweight or lean dogs.

### Discussion

By investigation of 2 sets of obese dogs (naturally obese versus experimentally induced), we confirmed a significant impact of obesity on CPF and quality of



**Fig 1.** Mean heart rate values recorded with a handheld pulse oximeter before the 6-Minute Walk Test (6MWT; T0), in the middle of the test (T3), and 0, 1, 2, 3, and 5 min after the end of the walk (T6, T7, T8, T9, and T11) in 12 dogs before (OBESITY), during (OVERWEIGHT), and at the end (LEAN) of the weight loss program.



**Fig 2.** Mean peripheral oxygen saturation values recorded with a handheld pulse oximeter before the 6-Minute Walk Test (6MWT; T0), in the middle of the test (T3), and 0, 1, 2, 3, and 5 min after the end of the walk (T6, T7, T8, T9, and T11) in 12 dogs before (OBESITY), during (OVERWEIGHT), and at the end (LEAN) of the weight loss program. \*\*\*means statistically significant different values in the obese group compared to both other groups;  $P < .05$ .

life in dogs. Subsequent BWL was associated with significant improvement in the 6MWT WD and several cardiopulmonary parameters before, during, and after the 6MWT. However, we failed to show any significant effect of obesity or subsequent BWL on arterial blood gas parameters.

One of our hypotheses was that the type of obesity (natural chronic obesity versus experimentally induced obesity) would influence the degree of CPF deterioration in severely obese dogs and possibly the pattern of improvement observed during BWL. However, none of the CPF parameters analyzed during this study were

significantly affected by the type of obesity. Therefore, all dogs used in this study were regrouped and discussed as only 1 group of obese dogs.

The only difference observed between these 2 groups of dogs (privately owned dogs versus experimental Beagles) was the mean time necessary to reach the targeted BW (32 weeks versus 22 weeks, respectively), especially during the second half of the BWL program. This was probably because of decreased owner compliance, which also was the cause of drop-out of 3 dogs that did not complete the BWL program. The reasons why 3 owners abandoned the study were behavioral

problems in the dog, the dog's hunger, or the owner's health problem.

When basic cardiopulmonary parameters were investigated in obese dogs, a clear tendency to increased resting RR was seen, which subsequently improved during BWL. Obese dogs also were panting more often in comparison to overweight or lean dogs. Therefore, even though RR values were not recorded in panting dogs, differences would have been even more accentuated if panting values had been included. This consequence of obesity is well described in human patients. Tidal volumes often are decreased in severely obese subjects, and breathing follows a rapid and shallow pattern to try to maintain a constant minute ventilation.<sup>9</sup> Global stiffening of the respiratory system with decreased compliance of lungs and chest walls is believed to be involved.<sup>9</sup> However, many possible mechanisms by which excess body fat might influence ventilatory function are discussed in the literature.<sup>21,22</sup>

Several veterinary studies using different techniques to evaluate lung function (barometric whole body plethysmography,<sup>7</sup> spirometry, or head-out plethysmography<sup>6</sup>) showed similar results in dogs. Decreased compliance has been suspected in obese dogs to explain this increased resting RR.<sup>7</sup>

Another interesting finding was a decrease in resting HR after significant BWL. Similar results have been reported in obese human patients.<sup>16</sup> Higher energy output required because of increased total body mass in conjunction with modified ventilatory function<sup>9</sup> could cause a relative oxygenation deficit and a compensatory increased heart rate in obese patients.<sup>16</sup>

Unexpectedly, arterial blood gas parameters were within normal limits<sup>23</sup> in our group of obese dogs. We also failed to demonstrate any significant effect of BWL on arterial blood gas parameters in our study as all parameters remained within normal limits during the study.

Our findings differ from those observed in humans. Indeed, some severely obese subjects showed lower arterial oxygen saturation as a possible consequence of decreased expiratory reserve volume and abnormal ventilation distribution.<sup>9</sup> In another study,<sup>12</sup> an extensive BWL of 45 kg (BMI =  $-13 \text{ kg/m}^2$ ) over a period of 18 months was associated with improvement in PaO<sub>2</sub> (by 10 mmHg, range 1–23) and a decrease in PaCO<sub>2</sub> (by  $-3 \text{ mmHg}$ , range 3 to  $-14$ ) in a group of morbidly obese human patients.

This discrepancy between arterial blood gas values in obese dogs and humans might be related to the low number of dogs included in the present study and some lack of statistical power. It was challenging to follow up client-owned dogs until an ideal BCS within an appropriate timeframe, and some dogs unfortunately were dropped from the protocol.

The technique used to collect the arterial samples in our patient also may be responsible for some increased variability and preanalytical errors in blood gas parameters. Occasional low values of PaO<sub>2</sub> may have resulted from venous contamination of some arterial samples. However, we wanted to evaluate CPF in a

clinical setting and more invasive techniques (eg arterial catheterization) were not deemed appropriate and could have interfered with the dogs' ability to walk normally.

Another possible explanation may be related to extreme obesity and extensive BWL observed in humans making changes in arterial blood gases more severe. This kind of obesity appears difficult to reproduce in dogs.

Furthermore, some of our patients, especially client-owned dogs, were not familiar with the veterinary hospital and appeared to experience stress as soon as they entered the premises. Firm handling was sometimes necessary to obtain the arterial blood sample, which probably amplified existing stress. Panting and some degree of hyperventilation in these dogs also may have influenced our results to some extent and could explain the observed discrepancy with human patients.

The natural tendency for panting in dogs in general also may be part of the explanation because panting was frequently observed in our group of obese dogs. This canine behavior could be compared to techniques of high frequency ventilation used in human pediatric medicine to improve blood gas exchange efficiency.<sup>24</sup>

Finally, specific anatomical differences in dogs may be implicated. In humans, increased abdominal mass because of fat tissue accumulation may decrease the downward movement of the diaphragm limiting lung expansion and inflation.<sup>9</sup> The quadruped posture of dogs may limit this ventilatory effect in obese subjects.

As previously reported,<sup>15</sup> the 6MWT was easy and safe to perform for all dogs in the study. It required very little time for dogs to acclimate to this noninvasive procedure. The 6MWT was found to be very safe in several other studies in which dogs with severe pulmonary disease<sup>15</sup> or induced cardiac failure<sup>25</sup> also were tested without complications.

Mean 6MWT WD in our group of obese dogs was  $509 \pm 35 \text{ m}$ , which was slightly lower than what has been reported in previous studies involving healthy nonobese dogs ( $522.7 \pm 52.4 \text{ m}^{15}$  and  $573 \pm 85.5 \text{ m}^{25}$ ). BWL was significantly associated with longer 6MWT WD in our study.

Increased BW in humans is known to negatively influence the 6MWT WD.<sup>16</sup> 6MWT WD also has been shown to correlate with maximal oxygen consumption (VO<sub>2</sub>max)<sup>26</sup> and health-related quality of life in human subjects.<sup>27</sup> A recent publication indicates that the 6MWT may be used in clinical practice to evaluate intervention success beyond kilogram weight loss in obese patients undergoing a weight reduction program.<sup>10</sup>

Recently, some detrimental changes in pulmonary function have been described in obese dogs,<sup>7</sup> but VO<sub>2</sub>max and quality of life were not evaluated in these dogs. Shorter 6MWT WD in obese dogs in our study may reflect these detrimental pulmonary function changes and may be associated with decreased respiratory well-being and decreased quality of life. Ideal BW was necessary to reach an optimal and significant improvement of WD.

However, obesity also seems to have an important impact on cardiac function in dogs<sup>3</sup> and human beings.<sup>28</sup> In addition, 6MWT WD was significantly decreased in dogs with heart dysfunction in 1 experimental study.<sup>25</sup> Therefore, our results should be interpreted with caution because improvement in 6MWT performance observed during BWL in our study also could be related to improvement of cardiac function. Echocardiography was not performed in our study to confirm this hypothesis. Consequences of obesity on cardiac function still remain unclear in human medicine, and some researchers have observed normal cardiac function in obese individuals.<sup>29</sup>

In our study, BWL also was associated with improvement in heart rate and oxygen saturation during and after the 6MWT. However, these results should be interpreted cautiously because high and variable pulse oximetry failure rates were observed in our study, especially in obese dogs.

Most studies evaluating pulse oximetry accuracy in dogs recorded SpO<sub>2</sub> relatively accurately over a wide range of normal saturation values.<sup>30</sup> However, these studies were performed on anesthetized dogs. In our study, dogs were not anesthetized. Many dogs were panting at midtest, during the recovery period or at both times. Therefore, motion artifact and lack of cooperation from the dog may explain our results and could be associated with underestimation of SpO<sub>2</sub> and inaccurate HRp. Furthermore, despite care to avoid pigmented mucous membranes in the buccal cavity, some dogs were very pigmented, and this factor seemed to be associated with increased failure rates.

Despite these limitations, our results are similar to what has been reported in human medicine. Indeed, normal weight human subjects have been shown to have a significantly better cardiopulmonary response during a treadmill 6MWT compared to a group of severely obese patients.<sup>16</sup> This observation may be explained by a blunted hyperventilation response during exercise, which has been well described in obese human subjects.<sup>12</sup> Such subjects do not increase their RR proportionally to their higher absolute peak VO<sub>2</sub>.<sup>16</sup> A combination of some degree of ventilatory deficit and high-energy output requirement in obese patients<sup>9</sup> could be responsible for a relative blood oxygenation deficit and a compensatory increased heart rate.

Similar ventilatory deficits recently have been suspected in obese Beagles<sup>7</sup> and might explain a relative oxygenation deficit in our obese dogs and the subsequent cardiovascular response observed during and after the walk. In our study, however, 50% of targeted BWL was sufficient to observe adequate mean HRp and SpO<sub>2</sub> as compared to overweight and lean dogs.

Finally, HRp and SpO<sub>2</sub> showed different recovery patterns in obese dogs in our study. A previous study<sup>15</sup> showed similar postexercise heart rate in healthy dogs and dogs with pulmonary disease, and there was no significant difference in HRp at any time point during the recovery period among obese, overweight and lean dogs. As for SpO<sub>2</sub>, although it was lower in obese

dogs at the end of the walk, a very quick recovery was observed with optimal values already seen 1 min post-exercise (T7).

Practically, monitoring SpO<sub>2</sub> after a 6MWT may be useful to monitor the effect of BWL on CPF but only within 1 min after exercise because of the quick recovery. On the other hand, heart rate monitoring at a specific time point within 5 min after exercise does not seem to be helpful, and only mean heart rate including all time points may be used.

## Conclusion

In conclusion, our results confirm that obesity in dogs negatively and significantly affects cardiopulmonary function as assessed by the 6MWT including heart rate and blood oxygen saturation monitoring during and after the walk.

Partial weight loss induces significant improvement in cardiopulmonary function even before dogs achieve their targeted ideal BW. However, 6MWT WD continued to improve until ideal body condition (BCS 5/9) was achieved. Therefore, results of the present study allow us to strongly recommend owners of obese dogs to target an ideal BW (BCS 5/9) for their dogs.

The 6MWT including heart rate and blood oxygen saturation monitoring, but not arterial blood gas analysis, was an efficient tool to demonstrate the efficacy of BWL to improve cardiopulmonary function and quality of life in dogs.

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## Footnotes

<sup>a</sup> Gault S, et al. Six-Minute Walk Test in Healthy Dogs/Reproducibility, Effect of Age and Breeds. In: ECVIM Congress, Toulouse, France, 2010

<sup>b</sup> Soehnle Professional GmbH & Co KG, Backnang, Germany

<sup>c</sup> Hill's Science Plan™ Canine Adult Performance, Hill's Pet Nutrition Inc, Topeka, KS

<sup>d</sup> Hill's Prescription Diet™ r/d™ Canine, Hill's Pet Nutrition Inc

<sup>e</sup> Blood Gas Monovette®, Sarstedt AG & Co, Nümbrecht, Germany

<sup>f</sup> AVL Omni 3, Roche Diagnostics®, Vilvoorde, Belgium

<sup>g</sup> Handheld pulse oximeter N-20PA™, Nellcor Puritan Bennett Inc, Boulder, CO

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*Conflict of Interest:* The authors disclose no conflict of interest.

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