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Upper airways resistance and snoring in anaesthetized dogs

J. G. Widdicombe, A. Davies*

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ABSTRACT: We have measured upper airways resistance from the trachea and from the pharynx to the atmosphere, EMG of genioglossus muscle, and the sound of snoring, in anaesthetized greyhounds breathing spontaneously through the upper airways. Using extra-corporeally produced continuous flow we determined flow/pressure curves for the upper airways in an expiratory direction and analysed them in terms of resistances from the trachea and from the pharynx. Resistances and other variables were determined with the nose open and the nostrils blocked. About one-third of the dogs snored spontaneously and most of the remainder did so when the nose was blocked. During snoring with nasal blockage the upper airways resistance increased considerably, and the sound of snoring and genioglossus EMG were also enhanced. The results show that the anaesthetized greyhound is a suitable model for studying snoring with simultaneous measurements of upper airways resistance and the activity of pharyngeal dilator muscles.
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Dept of Physiology, St George's Hospital Medical School, Cranmer Terrace, London, UK.

*Dept of Physiology, University Medical School, Teviot Place, Edinburgh, EH8 9AG, UK.

Correspondence: Prof. J. G. Widdicombe, Dept of Physiology, St George's Hospital Medical School, Cranmer Terrace, London, SW17 ORE UK.

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In man, snoring is recognized as a potential medical problem, possibly leading to obstructive sleep apnoea and progressive cardiovascular disease such as hypertension [1–4]. In addition it can be a social problem of serious proportions which are sometimes neglected because of humorous conotations. Medical and surgical treatments of snoring are developing rapidly, but some of the surgical interventions, which are undoubtedly necessary in severe cases, are formidable and most medical treatments require further research to test their efficacy.

Physiological studies in man have established that during snoring the pharyngeal cross-sectional area is reduced. If the pharyngeal dilator muscles contract less forcibly, intraluminal pressures that close the pharynx need to be less negative than usual to cause pharyngeal collapse during the inspiratory phase [5–7]. This results in increased upper airways resistance and vibration of soft tissue around the oropharynx which leads to the typical noise of snoring, as well as greater intrathoracic negative pressures in inspiration to overcome the increased oropharyngeal resistance. Snoring is normally prevented by contraction of the inspiratory dilator muscles of the oropharynx, which maintain upper airway patency [8, 9]. The physiological control of these muscles has recently been studied in man and experimental animals [8–12]. Another possibility, which has been little tested, is that the presence or absence of upper airway secretions and their chemical nature may lead to increased adhesiveness of the soft tissues of the upper airways [13, 14]. Furthermore, vibration of secretions in the upper airways may contribute to the sound of snoring.

To understand the mechanism of snoring it would be useful to have an animal model. Dog owners know well that members of the species snore, especially if the dog is old and fat; these last features may suggest a comparison with snoring in man [1]. Bradycephalic dogs have upper airways obstruction [15]. The sleeping bulldog snores, and sleep apnoeas and hypoxic episodes have been studied [16]; however, availability and expense may limit the use of the bulldog in snoring studies. We have, therefore, studied anaesthetized greyhounds breathing through the upper respiratory tract to see whether or not snoring occurred or could be induced, and the relationship between snoring and upper airway mechanics and genioglossus (airway dilator muscle) activity. A subsequent paper [17] describes changes in the measured variables that follow introduction of surface-active agents into the oropharynx.

Methods

Ten adult greyhounds of either sex were used (body weight range 26–32 kg). They were anaesthetized with intravenous sodium pentobarbitone (30 $mg \cdot kg^{-1}$ initially) and placed in a supine position. Blood pressure was recorded through a catheter in a femoral artery with a strain-gauge manometer. A femoral vein was catheterized for injection of supplementary doses of anaesthetic. An L-shaped plastic cannula was tied into the cervical trachea as caudal as possible in the neck, and a similar cannula was inserted pointing cranially below the larynx (fig. 1.); this was positioned with its tip 2–3 cartilage

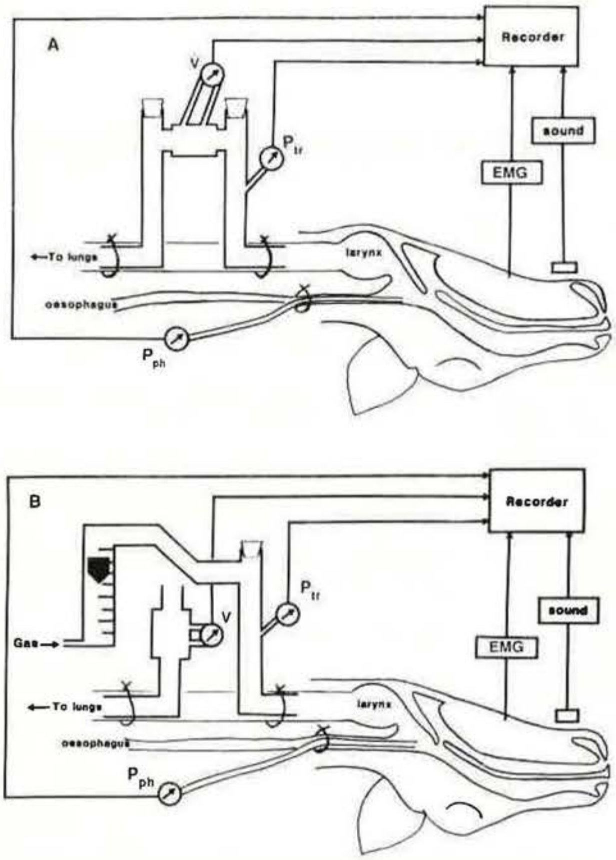

Fig. 1. – Diagram of experimental arrangements. (A) with the dog breathing through the upper airways; (B) with controlled flow through the upper airways to determine flow/pressure relationships. For details see text.

rings below the cricoid cartilage. Care was taken to avoid damage to the recurrent and pararecurrent laryngeal nerves. A plastic catheter, internal diameter 2 mm, was passed via the midcervical oesophagus into the oropharynx, where its tip could be observed via the mouth. It was tied in place by a snare around the oesophagus, sparing the laryngeal nerves.

The electromyogram (EMG) of the genioglossus muscle was recorded via two fine-wire hook electrodes, positioned with their tips about 5 mm apart. The sound of snoring was recorded with a microphone either attached to a canine tooth of the upper jaw or mounted about 2–3 cm away from the side of the mouth. Upper airways pressures were recorded through the air-filled pharyngeal catheter and through the side of the cranial tracheal cannula by strain-gauge manometers (Gould). Airflow was recorded by a Fleisch pneumotachograph. Airflow, tracheal and pharyngeal pressures, EMG and sound were all recorded on magnetic tape (Racal) and on recording paper (Gould).

Two experimental procedures were performed. In the first, the pneumotachograph connected the two tracheal cannulae so that the dog breathed through its upper respiratory tract (fig. 1A). In this condition most dogs did not snore, but snoring could be induced by closing the nostrils with gentle manual pressure. To prevent the accumulation of respiratory effects of nasal obstruction, this was performed for 1–2 breathing cycles about once every minute during experimental runs. On a few occasions the nostril on one side only was closed to induce snoring.

In the second procedure the dog breathed through the caudal tracheal cannula and the pneumotachograph (fig. 1B). The cranial tracheal cannula was connected to a rotameter and a compressed air cylinder, and air was blown through the upper repiratory tract in steps of $10 l \cdot min^{-1}$ from 0–60 $l \cdot min^{-1}$. Each step was held for about 20 s. At any constant flow rate, pressure varied with respiratory phase and peak inspiratory and expiratory pressures were measured. This allowed the preparation of flow/pressure curves for the upper respiratory tract for inspiratory and expiratory phases during constant expiratory flow. The procedure was carried out first with the nose open and then with the nose closed.

Analysis of results

Changes in the intensity of EMG and sound could usually be heard and seen clearly on the chart record. These were later quantitated by integration from the magnetic tape using half-wave rectification and a moving average integrator with a time constant of 200 ms [17]. Upper airways resistances were determined from the tracheal and pharyngeal pressure records and the airflow. The ratios of peak pressures to airflows were used to calculate resistances, which therefore corresponded to those at peak inspiratory and expiratory airflows.

The flow/pressure curves were graphically plotted. Their alinearity complicates the use of a single value for resistance (see Discussion). The sound recorded during production of a flow/pressure relationship was recorded as described above. Values given are mean±SEM.

Results

In three of the ten dogs breathing through their upper respiratory tracts, snoring was present from the beginning of the experiment; but in six dogs snoring occurred only when the nostrils were closed (fig. 2). The intensity depended on the position of the tongue. Pulling the tongue forward seemed to lessen snoring, so the tongue was left relaxed in the partially open mouth. Any tongue and jaw position was maintained throughout the experimental procedures. In one dog snoring never occurred, even with the nostrils closed, whatever the tongue position. In this dog lateral external pressure on the pharyngeal wall or extreme flexion of the neck induced snoring.

Spontaneous breathing through upper airways

Table 1 gives control values for total upper airways resistance from trachea and pharynx to the atmosphere, and "laryngeal resistance" in the inspiratory and expiratory phases, with the nose open and the nose closed. Laryngeal resistance was derived by subtraction of resistance recorded from the pharynx from that measured

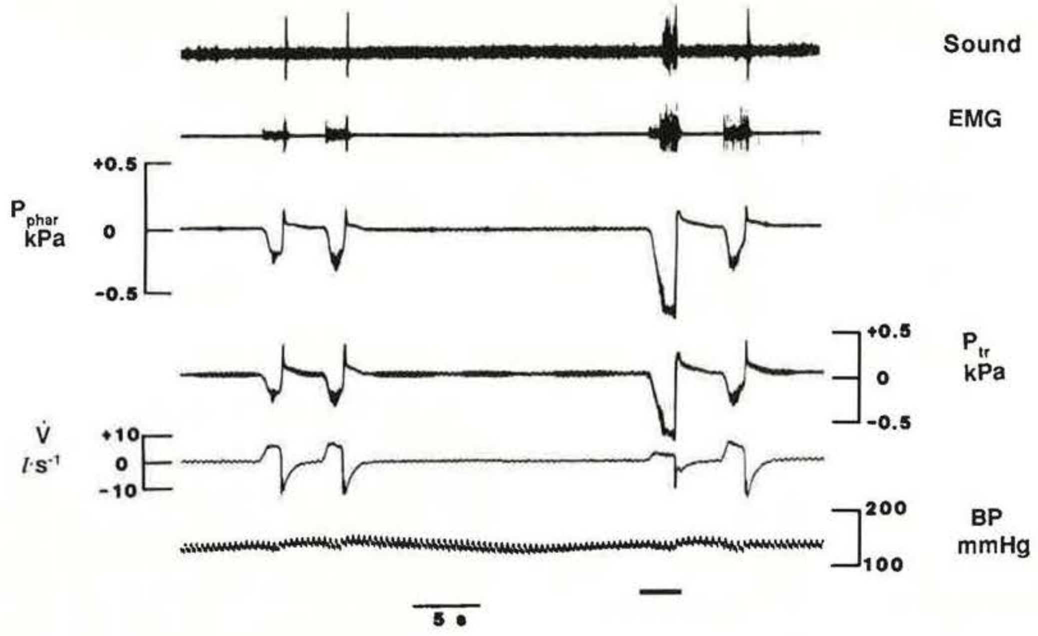

Fig. 2. – Record of physiological variables and sound of snoring. Traces from above down: sound, genioglossus EMG, pharyngeal pressure (Pph), tracheal pressure (Ptr), tracheal airflow (V) and blood pressure (BP). The dog was breathing spontaneously through its upper airway (as in fig. 1A). On the left-hand side of the record, two spontaneous breaths occur with EMG activity during inspiration, and with a sharp peak of EMG activity and of sound at the beginning of expiration. On the right-hand side, during the signal bar, the nostrils were closed for one breath, resulting in increased upper airway pressures and decreased airflow. At the same time inspiratory EMG was greatly enhanced, and the sound appeared strongly during inspiration.

Table 1. – Values of upper airway resistances measured during spontaneous airflow

		Resistances with pressure measurements from		
Condition	Respiratory phase	Trachea $kPa{\cdot}l^{-1}{\cdot}s$	Pharynx $kPa{\cdot}l^{-1}{\cdot}s$	Trachea-pharynx $kPa{\cdot}l^{-1}{\cdot}s$
Nose open	Inspiration	0.31±0.17	0.26±0.14	0.052±0.056
	Expiration	0.28±0.19	0.24±0.16	0.045±0.037
Nose closed	Inspiration	5.21±5.03	4.46±4.15	0.750±0.276
	Expiration	1.41±1.58	1.24±1.53	0.170±0.306

Means±SEM, n=8–10.

from the trachea. With the nose open, inspiratory and expiratory resistances were similar and laryngeal resistance was about one-sixth that of the total upper airways. When the nose was closed inspiratory resistances from the trachea and pharynx became 3–4 times larger than expiratory; the inspiratory laryngeal resistance became a smaller proportion (7%) of the total upper airways resistance. Laryngeal resistances were 4–15 times higher with nose closed compared to nose open, presumably because the segment of the airway between tracheal and pharyngeal pressure points included some collapsible oropharynx. When the nose was closed there was usually an increased sound of snoring, sometimes in both inspiratory and expiratory phases, and increased activity in the EMG of genioglossus in inspiration (fig. 2) with the nose open genioglossus EMG was sometimes active in the expiratory phase also.

Flow/pressure relationships

Figure 3 shows curves relating pressure to flow measured simultaneously from the trachea and from the pharynx in the inspiratory and expiratory phases with the nose closed (A and B), and with the nose open (C and D) in one experiment. A common feature of the relationships is that the flow/pressure curves are highly irregular in shape, usually showing a pronounced decrease in pressure (and therefore resistance) at the low or middle flow rates. As will be considered in the Discussion, this may be due to abrupt changes in the position of the epiglottis and of the soft palate. Figure 4 shows an experimental record of flow/pressure determination, selected partly because it illustrates marked irregularity of pressures and sound.

Table 2. – Values of upper airways resistances measured during continuous airflow

Condition	Respiratory phase	Resistances with pressure measurements from Trachea kPa·l^{-1}·s	Pharynx kPa·l^{-1}·s	Trachea-Pharynx kPa·l^{-1}·s
Nose open	Inspiration	0.20±0.04	0.13±0.03	0.055±0.021
	Expiration	0.22±0.02	0.18±0.02	0.044±0.011
Nose closed	Inspiration	0.42±0.10	0.34±0.10	0.047±0.019
	Expiration	0.44±0.05	0.38±0.04	0.086±0.016

Means±SEM, n=7–10. Values correspond to a flow rate of 1 $l·s^{-1}$ (60 $l·min^{-1}$).

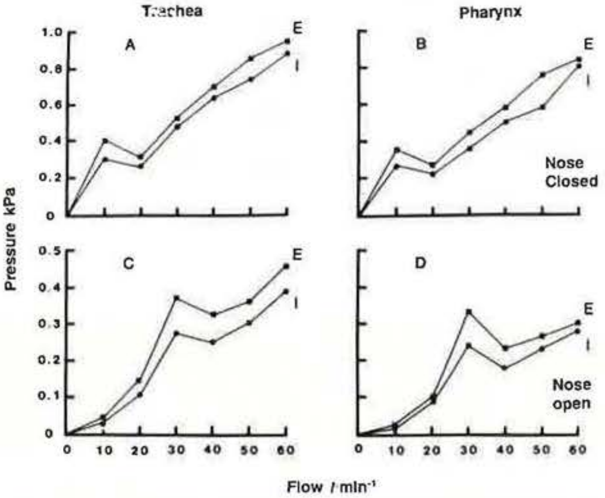

Fig. 3. – Flow/pressure curves drawn from a single experiment, with flows on the abscissa and pressures on the ordinate. On the left (A, C) pressures from the trachea, on the right (B, D) pressures from the pharynx. The upper records (A, B) show relationships with the nose closed, and the lower records (C, D) with the nose open. For each condition there are two curves, the upper one corresponding to pressures during expiration (E) and the lower one to pressures during inspiration (I). All curves show marked irregularities in the early (nose closed) or middle (nose open) parts of the ranges.

During measurement of flow/pressure relationships, genioglossus activity was usually absent or weak (fig. 4), but sometimes increased at higher flow rates or during irregularities of pressure patterns. Mechanical stimulation of the upper airways is known to cause reflex contraction of the pharyngeal dilator muscles [9, 11]. The sound of airflow appeared at the higher flow rates (fig. 4), especially when the nose was closed.

It will be clear from figure 3 that the irregularity of the flow/pressure curves does not allow the upper airways to be defined by a single resistance using this method. However table 2 presents mean results for "resistances" at the maximum flow rate of 60 $l·min^{-1}$, assuming linearity of the resistance relationship (*i.e.* measured pressure divided by 60 $l·min^{-1}$). Resistances were lower than those during spontaneous breathing through the upper airways. When the nose was closed resistances measured from the trachea and pharynx were approximately doubled; however, they were considerably lower than those measured during spontaneous airflow. The lower resistances measured during continuous compared to spontaneous airflow were presumably due to the fact that airflow at 60·min^{-1} in the expiratory direction would distend the oropharynx; this would prevent the collapse of this region

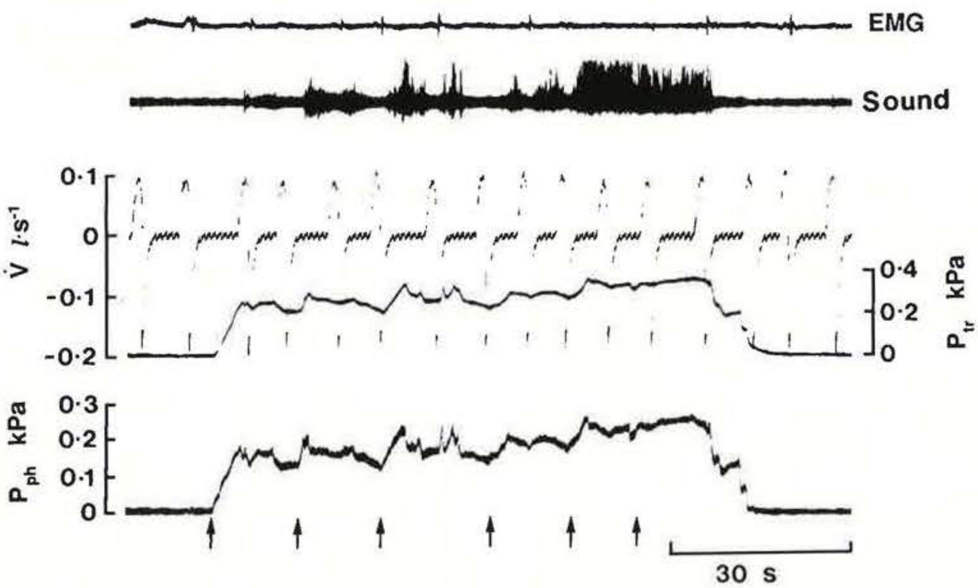

Fig. 4. – Record showing traces from which flow/pressure relationships were derived. Traces from above down: genioglossus EMG, sound, airflow ($\dot{V}$), tracheal pressure (Ptr), pharyngeal pressure (Pph), and blood pressure (BP). Flow was increased in steps of 10·min^{-1} up to 60·min^{-1} at the arrows. The pressure records show marked irregularity especially at the lower flow rates. At the higher flow rates sound appeared and increased. Genioglossus EMG was absent apart from weak inspiratory bursts of activity. During this record the nose was closed.

with high resistances especially during inspiration seen with spontaneous breathing when the nose was closed.

Discussion

The control of upper airways patency and resistance has been intensively studied in the last few years. This is partly because of the interest in the physiological mechanisms acting on upper airways muscles [8, 9, 11, 12] and also because of the importance of both obstructive apnoea and snoring; the latter may be a possible preclinical condition leading to more serious states [1–4]. Inevitably, most of the physiological studies of upper airways muscles have been with experimental animals, and most of the studies of obstructive sleep apnoea have been with man. For this reason there is an advantage in an animal model of snoring in which mechanisms of control can be analysed. Although there have been a number of studies on breathing in sleeping animals and on mechanisms of pharyngeal obstruction in anaesthetized animals [13, 18, 19], these seem to have been related to snoring for the bulldog only [16]. For this reason the model we have developed may be of value.

Snoring in anaesthetized greyhounds is rather similar to that in man, in that about one-third of the dogs snore spontaneously and most of the remainder do so when the nose is blocked [1, 20]. Occasional dogs will not snore under any circumstances apart from external obstruction of the airways or severe neck flexion. In the dog, gender seems to make no difference whereas in man snoring is more common in males [1]. We cannot say whether obesity is a factor influencing upper airways resistance and snoring since all the greyhounds we used were lean, presumably because of their lifestyle. The dogs were anaesthetized, whereas snoring humans are usually studied unanaesthetized but asleep; the airway control mechanisms in our study may therefore be quantitatively different from those in man.

The physics of upper airways "resistance" is formidable [8, 19]. Not only do maintained flow/pressure relationships show great alinearity (fig. 3) but, with spontaneous breathing through the upper airways, the pressure and flow records also have marked oscillations (fig. 2); this of course is to be expected because, almost by definition, snoring implies that the soft tissue elements of the upper airways are rapidly collapsing and distending, thereby imposing dramatic changes in spontaneous resistance as high as infinity when there is complete obstruction. For this reason, for spontaneous breathing we have only expressed our results as the peak inspiratory and expiratory resistances. Attempts to obtain meaningful values from pressure/flow loops displayed during spontaneous breathing through the upper airways were unsuccessful.

An additional problem is that pharyngeal pressure during spontaneous breathing is very low, especially when the nose is open. Also the pharyngeal catheter can easily become blocked with mucus. Hence N-values for pharyngeal pressures were sometimes smaller than those for tracheal. However, the results obtained with pharyngeal pressure were generally paralleled by those with pressures from the trachea below the larynx. The translaryngeal pressure was normally extremely low and may have included a component of the oropharynx due to the position of the pharyngeal catheter; there was no clear inspiratory decrease in "laryngeal" resistance, possibly because any decrease was counterbalanced by an increase in resistance due to collapse of this oropharyngeal segment.

The flow/pressure curves derived from continuous flow through the upper airways were highly irregular in shape (fig. 3), possibly because of sudden changes in the position of the epiglottis and the soft palate as flow was increased through the upper airways. In experiments in which resistances were not measured, these rearrangements could be seen by looking through the mouth. With this method it is possible to obtain resistances with the flow only in the expiratory direction; if negative pressure is applied to the upper trachea to draw air through the upper airways in the inspiratory direction, there is complete collapse of the oropharynx and larynx in the expiratory phase, with a ball-valve effect.

Tables 1 and 2 show that upper airways resistances are extremely variable, as indicated by the standard errors of the means. This is not surprising in view of the great variability of the geometry of the upper airways in natural and experimental conditions.

The sound of snoring can occur in both inspiratory and expiratory phases, although it is usually louder in the former (fig. 2). Dictionary definitions do not state that snoring has to be an inspiratory noise. The aerodynamics of continuous flow in an expiratory direction through the upper airways, producing a sound due to the air movement, is clearly very different from spontaneous flow through upper airways and natural snoring. Nonetheless, the continuous flow method has the advantage that flow rates are carefully controlled and resistance curves, although very alinear, can be plotted. Therapeutic or surgical methods which might change upper airways function could be tested by either or both methods.

In a subsequent paper [17] we describe the effect of a mixture of surface-active agents on the variables described here, and show that the model we have developed is suitable for studying the therapy of upper airways obstruction and snoring.

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RÉSUMÉ: Nous avons mesuré la résistance des voies aériennes supérieures entre la trachée et le pharynx d'une part et l'atmosphère d'autre part ainsi que l'électromyogramme du muscle génioglosse et les bruits de ronflement chez des lévriers anesthésiés. Nous avons également déterminé les courbes débit/pression pour les voies aériennes supérieures, en utilisant un débit continu, produit de façon extra-corporelle dans une direction expiratoire. Nous avons analysé l'ensemble en terme de résistance au niveau de la trachée et du pharynx. Les résistances et les autres variables ont été mesurées avec le nez ouvert et avec les narines bloquées. Environ 1/3 des chiens ronflaient spontanément et la plupart des autres le faisait lorsque le nez est bloqué. Les mesures de résistance ont montré qu'au cours du blocage nasal, avec ronflements, les résistances des voies aériennes supérieures augmentent considérablement et que le bruit de ronflement ainsi que l'électromyogramme du génioglosse sont stimulés. Les résultats montrent que le lévrier anesthésié est un modèle adéquat pour l'étude du ronflement avec des mesures simultanées des résistances des voies aériennes supérieures et de l'activité des muscles dilatateurs du pharynx.