A MANOMETRIC STUDY OF THE UPPER OESOPHAGUS IN THE DOG FOLLOWING CUFFED-TUBE TRACHEOSTOMY

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SUMMARY

Intraluminal oesophageal pressures were measured in dogs after tracheostomy and intubation with either uncuffed or cuffed tracheostomy tubes. Possible explanations for disordered swallowing following tracheostomy were found in those animals intubated with cuffed tracheostomy tubes:
(a) Increased intraluminal pressures were measured in the oesophagus at the level of the cuffs.
(b) Significantly increased pressures were found also 5 and 10 cm below the pharyngo-oesophageal junction. (c) The upper oesophageal sphincter relaxed incompletely.

Porter (1837) noticed food coming through a tracheostomy opening. Bryant (1861) reported a similar case in which milk escaped from the tracheal opening, and also made mention of a surgeon friend who, when he first observed this phenomenon, feared that he had injured the oesophagus during the operation.

Feldman, Deal and Urquhart (1966) stressed the adverse effect of accumulation of aspirated fluid and food above the cuff of the tracheostomy tube in three patients who had disordered swallowing following tracheostomy.

Some clarification of the function in the crico-pharyngeal and adjoining zones has been achieved by the measurement of intraluminal pressure (Fyke and Code, 1955; Atkinson et al., 1957; Sokol et al., 1966). The aim of the present study was to ascertain whether there were any pressure abnormalities in the physiology of deglutition in dogs following tracheostomy and tracheal intubation with low-pressure cuff tubes.

MATERIALS AND METHODS

The work was carried out at the Medical Sciences Building, University of Toronto, and satisfied both the Department of Veterinary Research of the University and the Ministry of Agriculture that no unnecessary suffering was inflicted on the experimental animals. The experimental set-up was regularly inspected and approved by a veterinary surgeon of the Animal Research Committee. The animals were fed twice daily (Roma) and their body weights remained steady. They were released from the cages twice daily for the tracheostomy tubes to be changed and cleaned and also for both the room and cages to be cleaned. During this time the dogs exercised freely. At the end of the study they were sacrificed using an overdose of sodium thiopentone i.v.

Tracheostomy was performed on 24 healthy mongrel dogs (17-20 kg). They were divided into five groups:
Group I: The trachea was intubated with uncuffed tracheostomy tubes (four dogs).
Group II: The trachea was intubated with soft, silicone cuffed tracheostomy tubes (experimental design) (four dogs).
Group III: The trachea was intubated with low-pressure foam cuffed tracheostomy tubes (Kamen and Wilkinson, 1971) (six dogs).
Group IV: The trachea was intubated with low-pressure Foregger cuffed tracheostomy tubes (Grillo et al., 1971) (six dogs).
Group V: The trachea was intubated with Foregger cuffed tracheostomy tubes, but the manometric studies were performed without the tubes in position (four dogs).

In each dog a low tracheostomy was performed under general anaesthesia using a single i.v. injection of 2% sodium thiopentone 20 mg/kg. The stoma was a vertical incision involving three to four tracheal rings, sited midway between the cricoid cartilage and suprasternal notch. All the tracheostomy cannulae had internal and external diameters of 7.0 mm and 9.0 mm respectively. The tracheal seal was tested twice daily using a Bennet respirator, the cuff being inflated to withstand an inspiratory pressure of 25 cm H_2O without leakage. The inflatable cuff was tested similarly at the times of performing the manometric studies. A 2.5-cm (i.d. 0.6 mm) polyethylene tube was placed in the lumen of the pilot tube of the
inflatable cuff. This addition to the pilot tube guarded adequately against the chronic escape of air from the cuff over the 24-hr period.

The trachea remained intubated for 2 weeks. The animal breathed spontaneously and was housed in an air-conditioned and humidified room during the period of intubation. Following this, the tracheal tube was removed and the tracheostomy wound was allowed to heal by primary intention.

The animals were sacrificed 4 weeks after extubation. At this time, the larynx, trachea, oesophagus and surrounding fascia were removed carefully en bloc. The relationship of the trachea to the oesophagus was retained after fixation in formalin. Serial sections were made of both structures for histological examination.

Pressure measurements were obtained using three PE240 polyethylene tubes. The lumen of each tube was obliterated distally and the tubes were fastened together to form a single assembly. A lateral hole was made in each tube at 5-cm intervals. The sites of the openings were marked with short radio-opaque strips. The catheter assembly was passed through a hole in a rubber bone placed in the conscious dog's mouth and its position in the oesophagus was determined fluoroscopically and manometrically. The animals were studied in the lateral position to facilitate fluoroscopic observations. The tubes were infused with water constantly at the rate of 3.6 ml/min/tube. Respiration was monitored with a Belt pneumograph fastened around the lower part of the chest. Changes in the intraluminal oesophageal pressure were measured using P23 De Statham strain gauges and recorded on a Honeywell 1508 Visicorder. The paper speed was 10 mm/sec. Tap water was dripped slowly into the back of the pharynx until the animal swallowed voluntarily the bolus of water which had accumulated in the pharynx. Continuous readings were made during staged catheter withdrawal, concentrating in the main on the upper one-third of the oesophagus, that is at the level of the cuff of the tracheostomy tube, the pharyngo-oesophageal sphincter and the intervening segment of the oesophagus. Sufficient time was allowed for measuring intraluminal pressures at each site during normal quiet breathing. The study ended when the distal lateral tube orifice entered the pharynx.

The zero pressure value was set to equal atmospheric pressure by opening each tube to the atmosphere. To determine the base line pressure (the tube pressure) from which intraluminal pressures were measured during the study, the resistance of each tube to forward flow of water was added to the zero pressure value.

Control studies were performed on each dog before the tracheostomy. Further studies were performed during the period of intubation, at 1 week and 2 weeks after tracheostomy, and then at 1 week and 3 weeks after extubation. A radio-opaque skin marker was placed over the proposed stomal site during the studies before operation. This marker was used to estimate fluoroscopically the level of the cuff. After extubation, a deformity was always found in the trachea at the stomal level and this was used also to locate the level of the cuff.

During the staged withdrawal of the catheter assembly, three pressure measurements (one from each tube) were made at each of the following sites: 5 and 10 cm below cuff level; at cuff level; 5 and 10 cm below the pharyngo-oesophageal sphincter; at the sphincter; and 5 cm above the sphincter (the pharynx). The mean pressures obtained at each level in the oesophagus were subjected to the paired t test, comparing the measurements obtained before operation with those made both during intubation and after extubation. In addition, each dog acted as its own control.

RESULTS

No dog died during the course of the study and, except for a small granulomatous area, the tracheostomy wounds were almost completely healed by the time the first extubation study was carried out.

Intraluminal pressures

(a) Oesophagus below "cuff" level and in pharynx. No significant changes in the resting intraluminal pressures were found in any of the groups of dogs.

(b) Oesophagus at "cuff" level. Comparing the pressure measurements before operation, no significant difference was found between the five groups. Also, in groups I and V (that is in the dogs with uncuffed tubes and in dogs after removal of the tracheostomy tubes) no significant difference was found between measurements made before operation and those made both during and after intubation. Intraluminal pressures were increased markedly \((P<0.001)\) during the intubation period in those animals intubated with either foam cuffs or the low-pressure Foregger cuffs (table I). By deflating the cuffs, the pressures were reduced, confirming that the increased intraluminal pressures were mainly a result of mechanical compression of the oesophagus by the cuffs (figs. 1 and 2). Unfortunately, the silicone
TABLE I. Mean oesophageal pressures (cm H₂O) at “cuff” level

<table>
<thead>
<tr>
<th>Group</th>
<th>Before operation</th>
<th>Intubation period</th>
<th>Exubation period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>SEM</td>
</tr>
<tr>
<td>III</td>
<td>11.2</td>
<td>4.4</td>
<td>1.8</td>
</tr>
<tr>
<td>IV</td>
<td>7.2</td>
<td>2.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Fig. 1. Increased intraluminal oesophageal pressure recorded by proximal catheter orifice (1) positioned opposite a Kamen-Wilkinson cuff in the trachea.

Fig. 2. (a) Proximal catheter orifice (1) at “cuff” level in the oesophagus; (b) deflation of Foregger cuff in the trachea; (c) reinflation of cuff in the trachea and (d) middle catheter orifice (2) positioned opposite cuff. (Paper speed 1 mm/sec.)

The catheter assembly entered the upper sphincter, both the lower orifices were well above cuff level. There was no significant alteration in the resting intraluminal pressure in this segment of the oesophagus in either group I (uncuffed) or in group V (tracheostomy) (P > 0.1).

When pressures before operation and after extubation were compared with the pressures measured during intubation (table I), intubation was found to be associated with an increase in intraluminal pressure at the 5- and 10-cm levels below the sphincter in groups III and IV.

When the Foregger cuff was used, the pressures at the 10-cm level were increased significantly (0.01 < P < 0.05) at both 1- and 2-week intubation studies. At the 5-cm level the increase became significant only after 2 weeks of intubation (0.02 < P < 0.05). With

(c) Oesophagus between cuff level and pharyngo-oesophageal sphincter. When the proximal orifice of experimental cuffs inflated asymmetrically and the pressures were dependent on whether the cuff had bulged anteriorly or posteriorly. However, resting intraluminal oesophageal pressures measured at the 2-week intubation study at the cuff level remained significantly increased (0.02 < P < 0.05) after deflation of the Foregger cuffs. There were no significant alterations (P > 0.1) in pressures measured at the cuff level after deflating the Kamen-Wilkinson cuff and those measured before operation and after extubation.
TABLE II. Mean oesophageal pressures (cm H₂O) 5 and 10 cm below the pharyngo-oesophageal sphincter

<table>
<thead>
<tr>
<th>Group</th>
<th>Before operation</th>
<th>Intubation period (1 week)</th>
<th>Intubation period (2 week)</th>
<th>Extubation period (1 week)</th>
<th>Extubation period (3 week)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>SEM</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>5 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>13.0</td>
<td>3.4</td>
<td>1.9</td>
<td>16.8</td>
<td>4.8</td>
</tr>
<tr>
<td>IV</td>
<td>11.0</td>
<td>3.9</td>
<td>1.7</td>
<td>13.7</td>
<td>6.3</td>
</tr>
<tr>
<td>10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>13.8</td>
<td>4.0</td>
<td>2.7</td>
<td>24.4</td>
<td>16.7</td>
</tr>
<tr>
<td>IV</td>
<td>16.2</td>
<td>5.3</td>
<td>2.2</td>
<td>29.8</td>
<td>14.1</td>
</tr>
</tbody>
</table>

the Kamen–Wilkinson cuff, the pressures at the 10-cm level were not significantly different ($P > 0.1$) and the differences at the 5-cm level became significant only after 2 weeks of intubation ($0.02 < P < 0.05$). Figure 3 shows the increased intraluminal oesophageal pressures recorded at 5 and 10 cm (leads 2 and 3 respectively) below the pharyngo-oesophageal sphincter (lead 1) in a dog after a 2-week period of intubation with the Foregger cuff. This increased resting intraluminal oesophageal pressure appears to affect the whole of the oesophageal segment lying between the “cuff” and pharyngo-oesophageal sphincter. This could be demonstrated by slowly withdrawing the recording orifices through this segment in the same dog (fig. 4).

No unco-ordinated motility or increased deglutition pressures were recorded in this segment of the oesophagus.

![Figure 3](image-url)

**FIG. 3.** Increased intraluminal oesophageal pressures 5 and 10 cm below the pharyngo-oesophageal sphincter during the intubation period.

![Figure 4](image-url)

**FIG. 4.** Staged withdrawal of catheter assembly. (A) middle catheter orifice (2) just below pharyngo-oesophageal sphincter; (B) middle catheter orifice at sphincter level.
(d) **Relaxation of the pharyngo-oesophageal sphincter.** Interpretation of pressure changes at the pharyngo-oesophageal junction is difficult because the pressure changes vary from dog to dog and even in the same animal depending, to some extent, on the posture and the size and type of bolus swallowed. Variation of pressures at the upper sphincter in the same subject depends also on the orifice orientation from which the pressure is recorded during the withdrawal of the catheter assembly through the sphincter (Winans, 1972). During swallowing there is the additional difficulty of maintaining the recording orifice in a constant relationship with the wall of the sphincter.

The degree of relaxation during deglutition at the sphincter was expressed as the percentage change in the resting sphincter pressure (fig. 5). This “percentage relaxation” was calculated from the pressures measured by each of the three recording orifices as the catheter was withdrawn; the means of these were used for comparison studies.

Insignificant changes in the “percentage relaxation” of the sphincter were recorded for groups I, II and V. Significant changes were seen in groups III and IV when studies before operation and during extubation were compared with the studies made during intubation ($P<0.01$ for the 1-week intubation study; $P<0.001$ for the 2-week intubation study) (table III).

Figure 6 shows the results of a preoperative manometric study of the pharynx (1), pharyngo-oesophageal sphincter (2) and upper oesophagus (3), and figure 7 the results of a study after 1 week of intubation with a Kamen–Wilkinson cuffed tube in the same dog demonstrating a decrease in the “percentage relaxation”.

In the majority of animals, the oesophagus was situated slightly to the left of the trachea at the cuff level on inspection of these organs *in situ* at the time of sacrificing the dogs. Except for the presence of fibrous tissue at stomal sites, both organs with surrounding fascia appeared histologically normal.

**DISCUSSION**

It is generally accepted that an intact neural arc is of prime importance in normal swallowing. Various possible explanations have been given for the

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**TABLE III. Mean percentage relaxation at the pharyngo-oesophageal sphincter**

<table>
<thead>
<tr>
<th>Group</th>
<th>Before operation</th>
<th>Intubation period</th>
<th>Extubation period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>SEM</td>
</tr>
<tr>
<td>I</td>
<td>88.7</td>
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</tr>
<tr>
<td>II</td>
<td>84.5</td>
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<tr>
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<td>79.7</td>
<td>10.1</td>
<td>4.1</td>
</tr>
<tr>
<td>IV</td>
<td>79.0</td>
<td>7.6</td>
<td>3.1</td>
</tr>
<tr>
<td>V</td>
<td>75.0</td>
<td>6.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

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**Fig. 5.** Showing how relaxation of the sphincter was expressed as a percentage.

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**Fig. 6.** Preoperative manometric study of pharynx, pharyngo-oesophageal sphincter and upper oesophagus.
disordered swallowing seen in some patients with a tracheostomy and in whom the neural arc is intact.

Feldman, Deal and Urquhart (1966) ascribed this to a desensitized larynx resulting from air bypassing this structure and also to compression of the oesophagus by the cuff in the trachea. Bonnano (1971), investigating patients with a tracheostomy using cinepharyngograms, showed a diminution of the elevation and anterior rotation of the larynx in the latter part of the second stage of deglutition in patients with disordered swallowing. He postulated that the tracheostomy tube had inhibited free up-and-down movements of the trachea and the laryngeal complex. Thus the muscles of the head and neck may contribute to sphincter opening. This view is supported by Asherson (1962), who noticed dysphagia for fluids in patients in whom the tracheo-oesophageal fascial plane was either involved in a severe inflammatory reaction or invaded by extensive malignant infiltration. This fixation of the trachea to the skin and anterior strap muscles can be seen also in patients who have a Björk flap tracheostomy, or severe peristomal inflammation.

Cameron, Reynolds and Zuidema (1973) claimed that the incidence of aspiration in surgical patients intubated with low-residual volume, non-yielding cuffed tracheostomy tubes was 69%. A more recent study has been made by the same authors using Foregger and Kamen–Wilkinson cuffed tracheostomy tubes in spontaneously breathing medical and surgical patients (Bone et al., 1974). They found the incidence of aspiration to be 17% when the Kamen–Wilkinson cuff was used and 15% with the Foregger cuff. They postulated that modification in tracheostomy tube and cuff design decreased the incidence of aspiration.

The low-pressure cuffs supposedly cause less deformation of the tracheal shape than the previous non-yielding, low-residual volume cuffs. Our studies show that the presence of the Kamen–Wilkinson or the Foregger cuff in the trachea causes a significant increase of the intraluminal oesophageal pressure.

The "percentage relaxation" at the upper oesophageal sphincter was reduced significantly after 2 weeks of intubation in those dogs with cuffed tracheostomy tubes, but not in the animals with only a tracheostomy or in those intubated with uncuffed tubes. This supports Asherson's and Bonanno's view that the presence of the cuff interfered with laryngo-tracheal movements. On the other hand, it is possible that the significant differences noted during intubation with cuffed tubes were caused by a relative impairment of oesophageal mobility during deglutition. In addition, an artefact may have been produced because the recording orifices could not maintain a constant relationship with the sphincter wall in the different groups. The third possible, although debatable, explanation of the observed impairment of relaxation is that there may have been a direct effect on the sphincter muscle, preventing proper "active" relaxation.

The cricopharyngeus appears to be the structure most responsible for closure of the pharyngo-oesophageal junction. However, recent studies suggest that there may be an "intrinsic sphincter" below the cricopharyngeus, which plays as large a role in effecting closure of the upper end of the oesophagus (Ingelfinger, 1958). Increased resting intraluminal pressures which appear to be dependent on the duration of intubation were found in the upper oesophagus between the tracheostomy cuff and upper sphincter.

ACKNOWLEDGEMENTS

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REFERENCES


ETUDE MANOMETRIQUE DE LA PARTIE SUPERIEURE DE L'OESOPHAGE SUR DES CHIENS, APRES UNE TRACHEOTOMIE AVEC CANULE A MANCHON

RESUME

On a mesure les pressions oesophagiennes intraluminales pendant la trachéotomie et le tubeage de chiens, à l’aide de canules de trachéotomie avec manchon ou sans manchon. On a trouvé, sur les animaux qui avaient été tubés à l’aide de canules de trachéotomie avec manchon, des explications possibles pour les déglutitions désordonnées survenant après une trachéotomie: (a) on a mesuré de plus fortes pressions intraluminales dans l'œsophage au niveau des manchons, (b) on a également trouvé des pressions sensiblement plus fortes entre 5 cm et 10 cm au-dessous de la jonction pharyngo-œsophagienne et (c) le sphincter supérieur de l'œsophage était incomplètement décontracté.

MANOMETRISCHE ERFORSCHUNGEN DER OBEREN SPEISEROHRE AM HUNDE NACH "CUFF-TUBE" TRACHEOSTOMIE

ZUSAMMENFASSUNG

Der intraluminale Speiseröhrendruck wurde an Hunden mit Tracheostomien und Intubation mit oder ohne "Cuff-tube" ermessene. Eine Reihe von möglichen Zusammenhängen der Schluckstörungen, die als Folge der Tracheostomie auftraten, mögen bei den Tieren mit "Cuff-tube" Intubation folgendermassen aufgezeichnet werden: (a) der erhöhte Intraluminaldruck in der Speiseröhre wurde an der Stelle des "Cuff" ermessene, (b) erhebliche Druckerhöhungen wurden auch 5 bis 10 cm unterhalb des pharyngo-oesophagalen Verbindungspunkts gemessene, (c) die Erschlaffung des oberen Speiseröhrensphinkters war unzureichend.

UN ESTUDIO MANOMETRICO DEL ESOFAGO SUPERIOR EN EL PERRO, DESPUES DE UNA TRAQUEOTOMIA DE TUBOS LIGADOS

SUMARIO

Se midieron las presiones esofágicas intraluminales en perros con traqueotomia y entubación con tubos de traqueotomia sin ligar y ligados. Se encontraron explicaciones posibles a la dificultad de la capacidad de tragar después de la traqueotomía en estos animales entubados con tubos ligados de traqueotomía: (a) se midieron presiones intraluminales crecientes en el esófago a nivel de los tubos ligados; (b) se encontraron también presiones notablemente crecientes de 5 y 10 cm por debajo de la articulación faríngeo-esofágica; (c) el esfínter esofágico se relajó de forma incompleta.