

Pathogenesis of tracheal stenosis following tracheostomy with a cuffed tube

An experimental study in dogs¹

M. GOLDBERG² and F. G. PEARSON

The Banting Institute and the Department of Surgery, University of Toronto, Toronto, Ontario, Canada

A study was undertaken to clarify the pathogenesis of tracheal stenosis complicating the use of cuffed tracheostomy tubes, a complication of increasing clinical significance.

Tracheostomy with a cuffed inflated tube was established in dogs and was maintained for two weeks. The effects of tracheostomy were assessed by bronchoscopy, tracheography, and histology at the time of killing, eight weeks after extubation. Animals were divided into four groups, each mimicking a common clinical situation. A control group had uncuffed tubes. A method was designed to determine the pressure developed between the cuff and the tracheal wall. Cuff inflation was maintained at low pressure and at high pressure in a second and third group of animals. A fourth group of animals received prednisone during the two weeks of low pressure inflation.

Tracheal stenosis, resembling the defect we have encountered in humans, occurred at the tracheostome in all animals. The greater the diameter of the tracheostomy tube relative to the tracheal diameter, the more severe was the resultant stenosis. Greater degrees of tracheal injury occurred with cuffed than with uncuffed tubes, and still greater injury was observed in animals in which high inflationary pressures or steroids were used.

These findings suggest that tracheal stenosis complicating cuffed tracheostomy tubes is the result of ischaemic death of tracheal cartilage due to pressure and infection. Steroids used concomitantly accelerate these changes.

HISTORY AND PATHOGENESIS

Colles (1886) reported that of 103 tracheotomies performed for diphtheria with 57 recoveries, four patients developed tracheal stenosis. Since that time, even with refined operative techniques and better postoperative care and management, tracheal stenosis following tracheotomy with cuffed or uncuffed tubes is still a hazardous complication reaching reported incidences of 1 to 20% (Falbe-Hansen, 1955; Aboulker, Lissac, and Saint-Paul, 1960; Paloschi and Lynn, 1965; Deverall, 1967; Johnston, Wright, and Hercus, 1967; Kucher, Lechner, Pokieser, and Steinbereithner, 1967; Pearson, Goldberg, and Da Silva, 1968a and b; Pearson and Fairley, 1970; Andrews and Pearson, 1971). Four types of post-tracheotomy tracheal stenosis have been identified, each presumably caused by similar as well as different factors—subglottic stenosis, stenosis at the level

of the tracheostome, stenosis at the level of the cuff, and stenosis at the tip of the tube.

Numerous factors have been associated with stenosis and have been reported as causes, but still the true aetiological agent has remained a mystery. Several investigators have tried to explain the pathogenesis of this phenomenon and others have tried to produce stenosis experimentally under controlled conditions.

CARTILAGE DOES NOT REGENERATE Schueller (1880) investigated the healing of the incised pig trachea and found that the cut edges of the cartilages united by a fibrous bridge and not by the regeneration of cartilage. Nelson (1958) also observed that cartilage does not regenerate after tracheotomy.

SIZE OF CANNULA Thost (1911) related the degree of stenosis to the size of the cannula. Nelson (1958) suggested that the presence of a cannula producing excessive granulation tissue could alone account for the stenotic lesion.

¹Supported by grants from the Medical Research Council of Canada and from the Ontario Cancer Treatment and Research Foundation, Toronto, Ontario

²Present address: The London Chest Hospital, London E.2, England

LOSS OF TRACHEAL SUPPORT Mori (1932, 1936) and Murphy, MacLean, and Dobell (1966) were unable to obtain a lesion by excising two tracheal rings subperichondrially, but Mori did find that severe stenosis would result if three or more rings were excised subperichondrially.

TIP OF CANNULA In 36 tracheotomies in victims of thermal burn injury, Teplitz, Epstein, Lawrence, and Moncrief (1964) found that all displayed a distinctive morphology of tracheotomy-cannula-induced tracheitis, a lesion occurring at the site where the distal end of the cannula abuts against the anterior tracheal wall. He traced the pathogenesis of necrotizing infectious focal tracheitis to the original mechanically initiated erosion which ultimately caused death in five of these patients.

TIGHT SUTURING OF WOUND Putney (1955) thought the principal cause of stenosis was tight suturing of the wound about the tracheotomy tube. This encourages peritracheal infection, perichondritis, and stenosis at the site of the tracheostome developing during the healing process.

HYPOXIA AND ALTERED TISSUE RESPONSE Little (1956) was the first investigator to incriminate hypotension as a factor influencing lesions at the tracheotomy cuff site. Stiles (1965) also suspected hypotension, vasopressors and vasoconstrictors, and steroids as factors influencing the severity of tracheal lesions at tracheotomy.

DURATION OF CANNULATION AND TYPE OF INCISION Nelson (1958) devised a thorough experimental investigation to assess the healing process after tracheotomy. He varied his tracheal incisions and developed an intricate method of measuring the tracheal stenosis produced. In animals with tracheal incisions but no cannula, no stenosis developed. Others were cannulated for 10 to 120 days and produced varying degrees of stenosis. He concluded that granulations vary according to the duration of intubation and not according to the type of incision used.

THE INFLATED CUFF There has been very little experimental work describing the effect that an inflated tracheotomy cuff exerts on the tracheal wall. Murphy *et al.* (1966) produced stenosis at the stoma in dogs by placing the inflated cuff *in the stoma* for seven days but found that they were unable to obtain a lesion with the inflated cuff in the trachea for 10 days. Cooper and Grillo (1969) produced varying circumferential, erosive lesions of the trachea experimentally at a cuff site in dogs within five days to two weeks by positioning a

conventional tracheotomy tube cuff endoscopically, without performing a tracheotomy, and inflating it at clinically used pressures. Thereby the effects of the creation of a tracheostome were avoided.

Since the combination of cuffed tracheotomy tubes and assisted ventilation has become popular in treating certain maladies, an increasing number of stenotic lesions have occurred at the level of the cuff. Johnston *et al.* (1967) found that of 12 stenoses in a group of 325 tracheotomies, seven occurred at cuff level. Gibson (1967) found that of 10 patients developing tracheal ulceration at cuff level, all 10 developed stenosis, and of 15 patients developing overdistension of the trachea at the cuff site during assisted ventilation, six developed stenosis. Andrews and Pearson (1971), in a two-year prospective study in patients who required tracheostomy with assisted ventilation in a respiratory failure unit, found the incidence of symptomatic tracheal stenosis was 17.5% in 103 patients. Twelve strictures developed at the level of the tracheostome and six at the level of the inflatable cuff. Data obtained from the study permitted anticipation of stenosis before the lesion actually developed. Without exception, the finding of circumferential mucosal ulceration at cuff level was a prelude to subsequent symptomatic stenosis. Other conclusions reached were that tracheostomy tubes of large diameter predispose to both stomal and cuff strictures; steroids predispose to stomal stenosis; and hypotension during the period of assisted ventilation and airway infection are probably significant factors.

Adriani and Phillips (1957) described an apparatus to correlate the intracuff pressure with the lateral pressure that an inflated cuff exerts on the tracheal wall. No relation whatsoever was found since the intracuff pressure is that pressure needed to overcome the elasticity of the cuff which is variable and much higher than the pressure exerted on the tracheal wall.

With the intention of finding the effects of a cuffed tracheotomy tube on the tracheal wall, an experimental study using dogs was carried out. Effects were anticipated at the tracheostome and at the level of the inflated cuff. Two variables were employed on control animals—the pressure that the cuff exerted on the tracheal wall and the use of high dose steroids while the tube was in place.

METHOD

A method was devised to estimate and control the pressure that an inflated tracheotomy cuff exerts upon the tracheal wall (Fig. 1). These pressures were

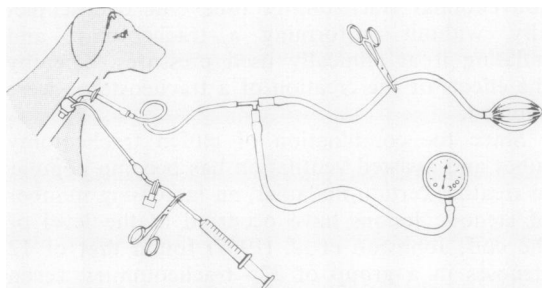


FIG. 1. Apparatus devised to measure and control the pressure that an inflated tracheotomy cuff exerts on the tracheal wall. See text for description.

regulated to approximate those used in clinical situations.

Inspiratory pressures are adjustable on present artificial ventilators, ranging on average between 15 and 40 cm of water pressure. The inflated cuff expanded against the tracheal wall must resist this pressure which develops in the tracheobronchial tree. Therefore 'leak' pressure represents an equilibrium between inspiratory pressure and the pressure exerted by the cuff on the tracheal wall.

Dogs with cuffed tracheotomies, anaesthetized with thiopentone sodium (Pentothal), were ventilated with a Bennett respirator and the cuffs were inflated to produce varying inspiratory pressures ranging from 5 to 60 cm of water. After each determination these dogs were immediately checked by our own device, and the cuff was allowed to remain inflated at the same pressure. To stop breathing efforts the dogs were hyperventilated for one minute with an Ambu bag applied directly to the tracheotomy tube and then an airtight rubber connector was fitted into the tube. This rubber connector was attached by a T-tube arrangement to both a pressure manometer and the Ambu bag. The dog's lungs were then inflated. At the end of each compression of the Ambu bag a haemostat was applied to the tubing to prevent the accumulated air from escaping from the lungs. This was repeated until a leak pressure was heard as well as seen on the manometer. In all instances this was the same as the leak pressure initially found with the Bennett respirator.

Therefore, by initially overinflating the cuff, inflating the dog's lungs to a pressure greater than that desired, and slowly deflating the cuff in small increments, any leak pressure desired could be obtained. This was presumably the pressure exerted by the cuff on the tracheal mucosa. The pressure was then maintained by a small clamp positioned on the connector tube of the cuff.

Tracheotomy was performed on adult dogs (anaesthetized with pentobarbitone sodium (Nembutal)) varying in weight from 15 to 40 lb (6.8 to 18.1 kg). It was observed that the greater the weight of the dog, the larger the tracheal diameter. A no. 8 Engström silver cannula was used consistently with either a Rusch

$\frac{1}{2}$ " (12 mm) or a Marrant-Baker 39/42 disposable cuff. The site of the stoma varied from ring 2 to ring 4 and at times two rings had to be incised in order to accommodate the tube. During the 14 days that the cuffs were continuously inflated, the pressures were checked or remeasured every two to three days using Pentothal anaesthesia; tracheal secretions were obtained for culture and sensitivity once weekly and bronchoscopic as well as digital inspection of the tracheal lumen was undertaken once weekly or when indicated.

At extubation the trachea was again digitally palpated and bronchoscoped. By injecting Hytrast into the tracheostome, tracheograms were obtained. The dogs were examined bronchoscopically at weekly intervals thereafter until they were killed 33 to 69 days after extubation. The time of death was determined by visualizing the trachea bronchoscopically and killing the dog when the degree of stenosis remained constant and the active healing process was minimal. Each trachea was fully epithelialized microscopically. After death tracheograms were taken and the superior thyroid artery was injected bilaterally with coloured latex in order to outline the vascular pattern of the tracheal submucosa. Latex injections were performed on normal dogs to outline the normal pattern. Photographic and histological slides of the trachea were taken. Evidence of tracheal stenosis was sought at the tracheostome, the level of the cuff, and the tip of the Engström cannula.

This method of investigation was carried out on four groups of dogs. Group A (3 dogs) had tracheotomies with uncuffed tubes; group B (10 dogs) had pressures between the cuff and trachea maintained at 45 cm of water; group C (14 dogs) had pressures maintained at 60 cm of water; and group D (10 dogs) had pressures maintained at 45 cm of water and received high doses of steroids given as 10 mg/kg of hydrocortisone intramuscularly daily for the 14 days of intubation and decreasingly smaller doses in the weaning period thereafter. Either the classical window incision, in which a square portion of the anterior tracheal wall is removed, the H-shaped incision, or a combination of both were used.

EXPERIMENTAL RESULTS

Airway infection developed in all dogs and the organisms cultured were similar to those from human airways in patients with tracheotomies. No method of humidification was used in the study and in considering our observations it is not possible to state what role lack of humidification has played in the pathogenesis of the changes observed.

Tracheal swabs grew a variety of organisms, the most frequent being *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Klebsiella*, *Entamoeba coli*, and *Bacillus proteus*. *Ps. aeruginosa* was seldom the first bacterium to be cultured from any one dog and behaved as a saprophyte, reproducing only after the trachea had been initially prepared by other bacteria. Stomal infections tended to be more severe in the high

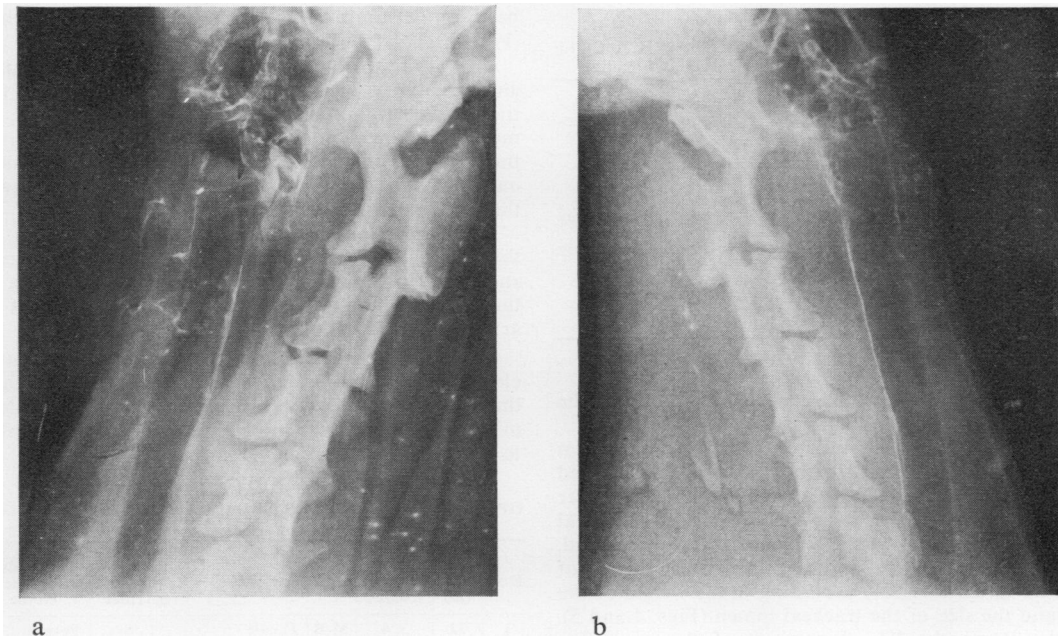


FIG. 2. Tracheograms of a 31-lb. dog of group A: (a) at extubation. At this stage no stenosis or granulation tissue is seen intraluminally; (b) 33 days after extubation, showing minimal stenosis at the level of the tracheostome.

pressure and steroid groups and were related to the degree of stenosis produced in all groups after the infection had subsided and the stoma had healed.

GROUP A (Table I) During tracheotomy these animals produced no significant amounts of tracheal secretions and the inner cannula had to be cleaned only at two-day intervals. Bronchoscopy at this time revealed a hyperaemic mucosa with an occasional erosion at the tip of the tube.

All three dogs with uncuffed tracheotomy tubes survived and developed tracheal stenosis at the tracheostome—two mild and one moderate (Figs. 2 and 3). The stenosis resembled that produced in dogs with cuffed tubes. One also had a step-like defect on the

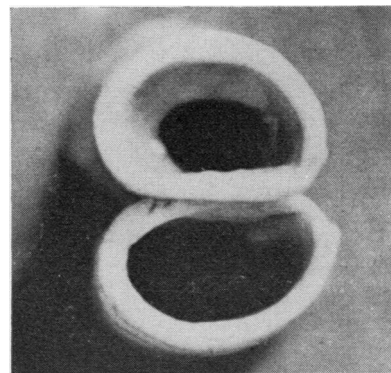


FIG. 3. Cross-sections through the tracheostome above, and the normal trachea below, in a 17-lb dog of group A 33 days after extubation. At tracheotomy a two-ring window was created to accommodate the no. 8 Engström cannula. The membranous surfaces are approximated and a mild to moderate anterolateral stenosis is present at the stoma. All surfaces are epithelialized.

TABLE I

GROUP A—3 SURVIVORS FROM 3 DOGS WITH NO CUFFS

Dog	Wt. (lb)	Rings Excised	Cuff	Cultures	Extubation to Sacrifice	Stenosis at Tracheostome
1	32	3	—	<i>E. coli</i> <i>B. proteus</i> <i>Staph. aureus</i>	53 days	Mild
2	31	3	—	<i>Staph. aureus</i>	33 days	Mild
3	17	3, 4	—	<i>Staph. aureus</i>	33 days	Moderate

anterior tracheal wall at the tip of the cannula but it was not severe enough to produce stenosis. The latex injections revealed a uniform mucosal vascular pattern resembling that of normal animals without tracheotomy. Tracheograms indicated that the stenosis began after extubation.

GROUP B (Table II) Tracheotomy produced mild to moderate amounts of secretions and necessitated inner cannula changes once daily. Bronchoscopy during the period of intubation demonstrated mucosal hyperaemia with relative pallor occurring at the cuff level as well as slight dilatation of the tracheal wall.

TABLE II
GROUP B—6 SURVIVORS FROM 10 DOGS WITH A CUFF
PRESSURE OF 45 cm H₂O FOR 14 DAYS

Dog	Wt. (lb)	Rings Excised	Cuff	Cultures	Extubation to Sacrifice	Stenosis at Tracheostome
1	40	3	M-B	<i>Staph. aureus</i>	42 days	Mild
2	35	2, 3	R	<i>Ps. aeruginosa</i>	64 days	Mild
3	35	2, 3	R	<i>Ps. aeruginosa</i>	69 days	Mild
4	24	4	M-B	<i>Staph. aureus</i> <i>Strep. fecalis</i>	42 days	Moderately severe
5	19	3	M-B	<i>E. coli</i> <i>Klebsiella</i>	48 days	Moderately severe
6	15	3, 4	R	<i>Staph. aureus</i> <i>Staph. aureus</i> <i>Klebsiella</i>	43 days	Severe

M-B=Morrant-Baker; R=Rusch.

Occasional mucosal erosion occurred at the tip of the tube.

Of the ten dogs with inflated cuffs exerting 45 cm of water pressure against the tracheal wall six survived and four died of plugged cannulae 2 to 10 days after tracheotomy. All six survivors developed tracheal stenosis at the level of the tracheostome—three mild, two moderately severe, and one severe. The degree of stenosis varied inversely according to the weight of the dog and the size of the tracheal lumen (Figs. 4 and 5). At the stoma the lateral portions of the remaining cartilages excised at tracheotomy were collapsed medially and the intercartilaginous fibrous tissue had contracted, forming a wedge-shaped lumen with the

base on a normal posterior membranous trachea (Fig. 4b).

Five of the six dogs developed a small area of injury, an irregularity or step, in the anterior wall of the trachea five to six rings below the stoma, caused by mechanical abrasion of the cannula tip during the time the tube was in place (Fig. 6). The mucosa and submucosa overlying these cartilaginous rings appeared thin in the gross specimen.

Latex injections indicated that the vasculature of the tracheal mucosa between the stoma and the cuff and distal to the cuff were normal, but the mucosa at the cuff level was ischaemic and relatively deficient of arterioles and capillaries.

GROUP C (Table III) An increase in the cuff pressure clearly produced more adverse changes in the trachea than low cuff pressures. Bronchoscopy done intermittently during the period of intubation was similar to that observed in group B.

TABLE III
GROUP C—2 SURVIVORS FROM 14 DOGS WITH A CUFF
PRESSURE OF 60 cm H₂O FOR 14 DAYS

Dog	Wt. (lb)	Rings Excised	Cuff	Cultures	Extubation to Sacrifice	Stenosis at Tracheostome
1	22	3, 4	M-B	<i>E. coli</i> <i>Klebsiella</i>	51 days	Severe
2	19	4	M-B	<i>Staph. aureus</i> <i>Haemolytic streptococcus</i>	44 days	Moderate

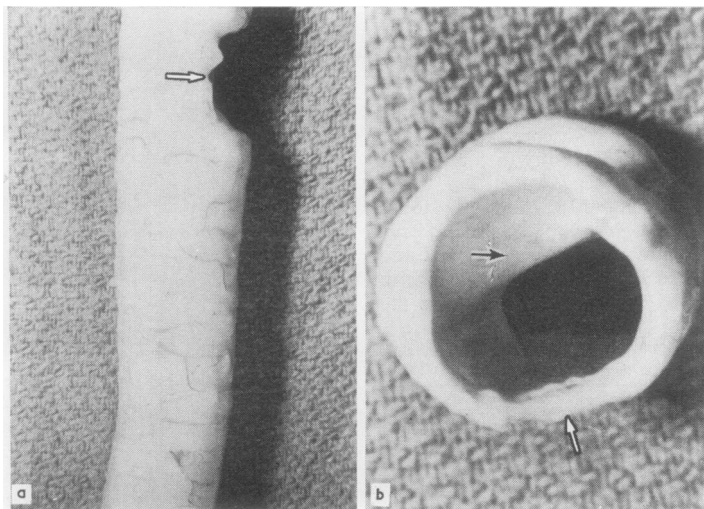


FIG. 4. The trachea of a 40-lb. dog of group B 42 days after extubation. One tracheal ring was excised at tracheotomy. There is a mild luminal stenosis and the animal was asymptomatic. Loss of cartilage and tracheal support is evident anteriorly (a) and the white arrow indicates the anterior defect at the tracheostome. There is a 50% luminal stenosis anteriorly (b) with an intact membranous trachea. All surfaces are totally epithelialized. The black arrow indicates the anterior defect and the white arrow points to the intact posterior membranous trachea.

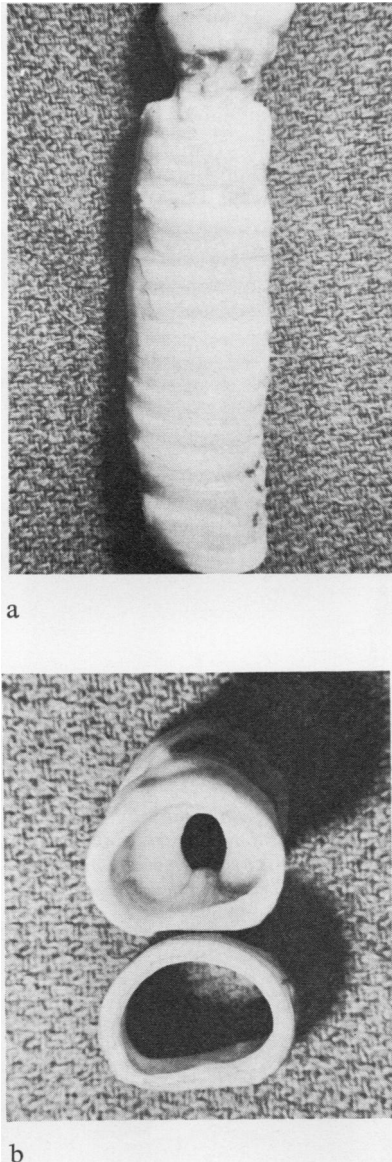


FIG. 5. The trachea of a 19-lb. dog of group B 48 days after extubation. One tracheal ring was excised at tracheotomy. The same size of cannula was used as in the dog shown in Fig. 4 but (a) there is extensive loss of cartilage and support over the length of at least two tracheal rings, producing a severe anterolateral defect. (b) Cross sections of the trachea show reduction of the luminal surface area of more than 75%. This stricture was classified as severe: the dog was symptomatic, having stridor at rest and being inactive. The stenosis is predominantly anterolateral and the membranous trachea is normal but puckered due to scar contracture approximating the lateral walls.

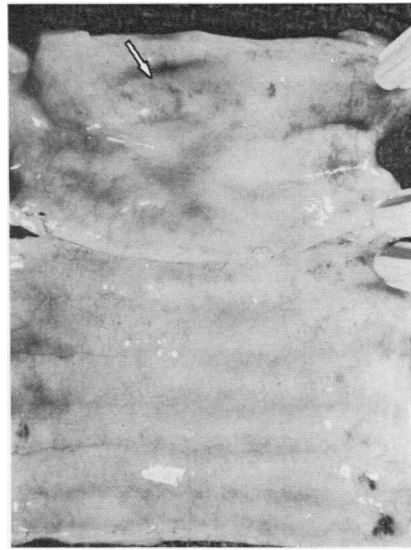


FIG. 6. The inner aspect of the trachea of a 19-lb. dog of group B 44 days after extubation. The arrow illustrates the defect at the tip of the cannula, five to six rings below the stoma, caused by mechanical abrasion of the cannula tip during the period the tube was in place.

Of the 14 dogs with cuff pressures at 60 cm of water, only two survived, 11 dying one to eight days postoperatively of plugged cannulae and one dying during bronchoscopy of an anaesthetic overdose.

Acute haemorrhagic tracheitis with excessive exudation was responsible for those dogs dying with plugged cannulae. The area of tracheitis was most marked distal to the cuff and between the stoma and the upper edge of the cuff. The area covered by the cuff appeared protected from the inflammatory reaction. This was observed in both the gross and microscopic specimens (Fig. 7).

The mucosa overlying the remaining rings adjacent to the tracheostome also displayed a pattern of changes. Dogs dying one or two days postoperatively had healthy mucosa overlying the cartilages adjacent to the tracheostome (Fig. 8). The mucosa in contact with the tracheotomy tube was hyperaemic and oedematous and beginning to ulcerate and expose cartilage. Dogs dying after three days showed increasing mucosal denudation of the remaining ring and rings just above and below the stoma. Such exposed cartilage inevitably dies, leading to an extensive loss of anterior and lateral structural support. These observations (Fig. 9) suggest that the type of tracheal incision used for tracheotomy is much less important than the actual diameter of the tracheotomy tube in determining the extent of the subsequent cartilaginous defect in the tracheal wall. Also, the greater the duration of cannulation, the greater the degree of mucosal denudation of cartilage.

Both survivors developed wedge-shaped stomal

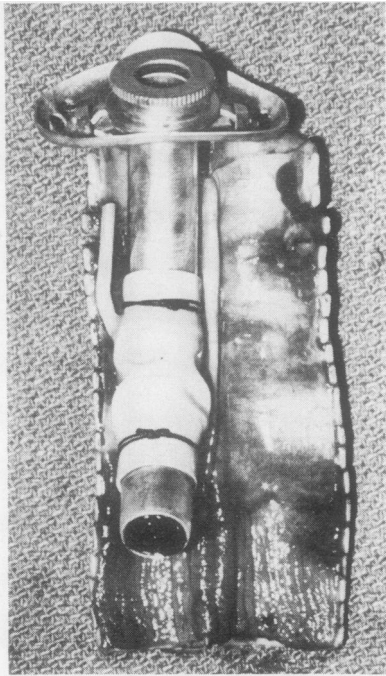


FIG. 7. The trachea of a 35-lb. dog of group C that died one day after tracheotomy due to a plugged cannula. The trachea is opened anteriorly with the cuffed tube in place. Acute haemorrhagic tracheitis is most pronounced distal to the cuff and between the upper margin of the cuff and the tracheostome. The tip of the tube is plugged with thick, tenacious, sanguopurulent secretion.

stenosis with anterolateral defects similar to those of group B—one moderate and one severe. One dog also developed a mild fibrous anterolateral stricture at the tip of the cannula as well as the stomal stenosis (Fig. 10a). At the time of extubation heaped up granulation tissue was evident on the anterior wall of the trachea, partially occluding the tracheal lumen as well as the lumen of the cannula (Fig. 10b). Figure 10c shows the tracheogram 44 days after extubation and the degree of stenosis at each level is illustrated (Figs 10d and e). This form of tracheal injury with ensuing stenosis at the tip of the cannula has been reported to occur in clinical patients by several authors (Johnston *et al.*, 1967; Teplitz *et al.*, 1964; Gibson, 1967).

TABLE IV

GROUP D—1 SURVIVOR FROM 10 DOGS WITH A CUFF PRESSURE OF 45 cm H₂O AND STEROID THERAPY FOR 14 DAYS

Dog	Wt. (lb)	Rings Excised	Cuff	Cultures	Extubation to Sacrifice	Stenosis at Tracheostome
1	30	3	R	<i>Ps. aeruginosa</i> <i>Staph. aureus</i> <i>B. protaus</i> <i>Klebsiella</i>	58 days	Mild

No injury in this group was found at the cuff site. Had the remaining animals survived, it is possible that injury at the cuff level might have developed in dogs dying with acute haemorrhagic tracheitis and obstruction of the tracheotomy tube.

GROUP D (Table IV) Ten dogs were subjected to tracheotomy with cuff pressures of 45 cm of water and high doses of steroids for 14 days.

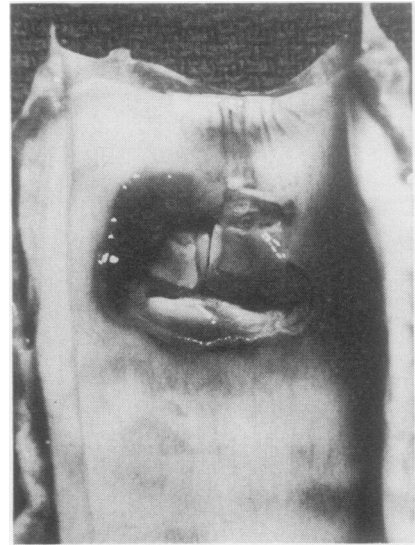


FIG. 8. The trachea of a 35-lb. dog of group C that died of a plugged tube two days postoperatively. The inner aspect of the H-shaped tracheostome illustrates that the mucosa in contact with the tube is hyperaemic and oedematous and is beginning to ulcerate and expose cartilage.

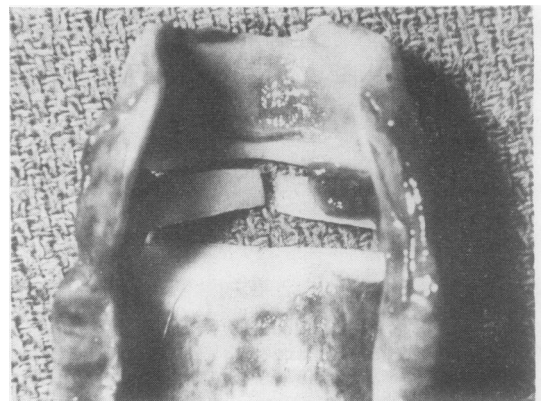


FIG. 9. The inner aspect of an H-shaped tracheostome in a 24-lb. dog of group C eight days postoperatively. The mucosa in contact with the cannula has disappeared, exposing bare cartilage. Such exposed cartilage will inevitably die, leading to an extensive loss of anterior and lateral structural support.

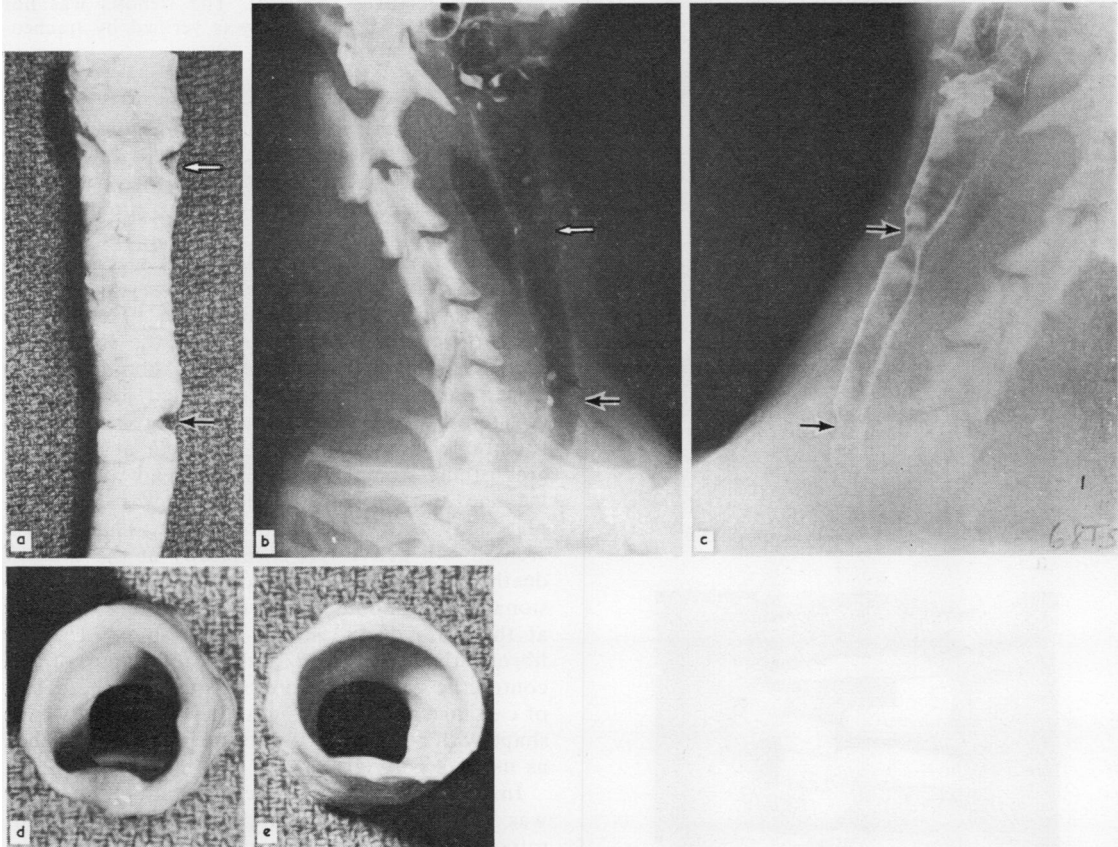


FIG. 10. (a) The trachea of a 19-lb. dog of group C 44 days after extubation. The white arrow indicates a moderate anterolateral defect at the stoma and the black arrow shows a similar defect produced at the tip of the cannula anteriorly. (b) The tracheogram of the same dog at extubation. The white arrow points to the stoma and the black arrow points to granulations at the tip of the tube on the anterior wall. Note that there is no luminal stenosis at the tracheostome at this time. A moderate anterolateral stenosis developed within 44 days of this extubation (see Fig. 10c). (c) A repeat tracheogram in the same dog 44 days after extubation. Moderate anterolateral stenosis is evident at two levels—the upper at the stoma and the lower at the level of the tip of the cannula. (d) Cross-section of the top stricture at the tracheostome in Fig. 10a. There is a moderate anterolateral defect with preservation of a normal posterior membranous trachea. (e) Cross-section of the bottom stricture at the level of the tip of the cannula in Fig. 10a. The defect at this lower level is also anterolateral.

Only one dog survived. Of the others, five died of plugged cannulae one to three days postoperatively, and four died of pneumonia 5 to 10 days postoperatively in spite of receiving adequate doses of penicillin and streptomycin.

The nine dogs that died unexpectedly provided interesting and valuable information at necropsy. All nine had acute haemorrhagic tracheitis and four had diffuse bronchopneumonia and pleural effusions. The organisms grown from bronchial aspirates included *B. proteus*, *Klebsiella*, *Staph. aureus*, *E. coli*, *Strept. faecalis*, and non-specific *Clostridia*. The damage produced at the stoma by the cannula far exceeded that produced in the other groups. The denudation of adjacent cartilages was more extreme and occurred

more quickly. At times extensive loss of mucosa occurred over the area on which the cannula had lain (Fig. 11 a and b). On gross inspection, the area beneath the cuff was relatively protected from the acute inflammatory process in the mucosa and submucosa present elsewhere. In this experimental study no evidence of peritracheitis was observed, as has been reported in some clinical cases (Florange, Muller and Forster, 1965).

The one survivor developed a typical wedge-shaped stomal stenosis which was mild in nature. An area of thinned mucosa and submucosa was present on the anterior tracheal wall at the tip of the cannula but there was no disruption of the cartilage. Latex injections indicated that the mucosal vasculature at cuff

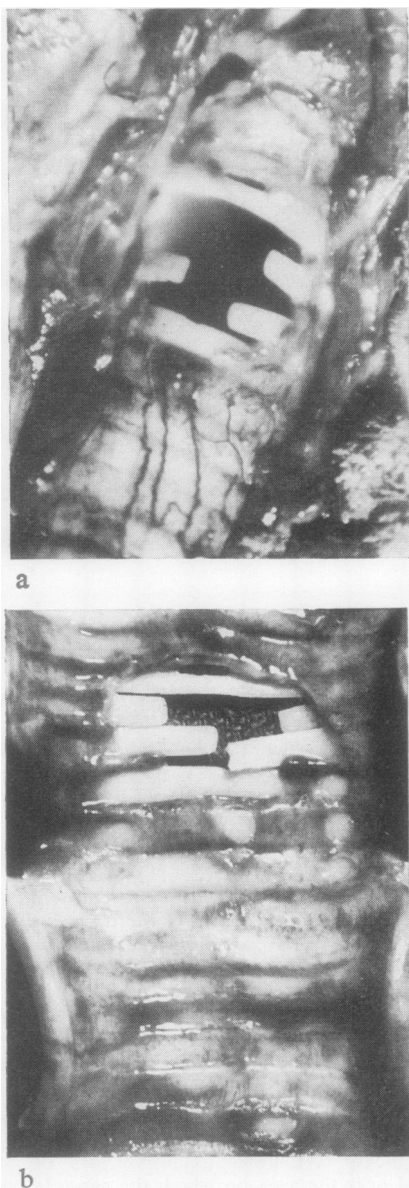


FIG. 11. (a) The external aspect of the tracheostome seven days postoperatively in a 37-lb. dog of group D with a combination window and H-shaped incision. There is extensive exposure of cartilage about the margins of the tracheostome. Normal reparative processes are absent, as evidenced by little fibrin or granulation tissue. (b) The inner aspect of the trachea in the same dog. Extensive ulceration of the mucosa is present with exposure of cartilage at all points of contact with the tracheotomy tube. The anticipated loss of cartilage in this dog extends over a length of at least six tracheal rings. Had the dog survived, an extreme anterolateral defect would be expected.

level was relatively deficient. The stenosis was not present at extubation which was verified by tracheograms and by bronchoscopy.

MICROSCOPIC RESULTS

When dogs were killed or died of plugged cannulae or pneumonia, histological slides of the trachea from the areas of the stoma, cuff level, and sections caudal and cephalad to the cuff level were obtained.

In all survivors a typical pattern was observed at the healed tracheostome with varying degrees of severity. Exuberant granulation tissue in the form of small fibroblasts invaded the stoma and cartilage did not regenerate. The submucosa was absent and the fibrous contracted bridge was covered with epithelium having undergone squamous metaplasia. The cartilage at the margins of the stoma was dying or dead with empty lacunae and, in varying degrees, was being replaced by active granulation tissue. This process seemed still active microscopically at the time of death, five to nine weeks after extubation. Occasionally the submucosa over the living cartilage at the sides of the stoma was also replaced by fibrous tissue (Figs 12 and 13). Because of the contractile nature of fibrous tissue and the defect of cartilage anteriorly, the lumen assumed a wedge shape with an intact posterior membranous trachea as its base (Fig. 4b).

In all killed specimens active granulation tissue was in the process of replacing cartilage. This raises the possibility of vascular granulations continuing to destroy viable cartilage in the period following extubation and when the effects of pressure and infection are no longer present.

The replacement of cartilage at the stoma was most severe in dogs having cuffs inflated at high pressures. The mechanism of the cuff which is the responsible factor is possible interference with circulation in the tracheal wall between the cuff and the stoma, which renders the intervening trachea ischaemic and more susceptible to infection and necrosis.

In survivors with step-like defects or stenosis occurring at the tip of the cannula on the anterior wall of the trachea, similar changes occurred. In mild lesions the ring at this level was displaced, the submucosa irregular and deficient, and the mucosa very thin or absent. In more severe lesions the cartilage had undergone necrosis and was being replaced by active granulation tissue (Fig. 14).

In all dogs dying with plugged cannulae, acute haemorrhagic tracheitis was observed. In the trachea most severely involved, distal to the cuff,

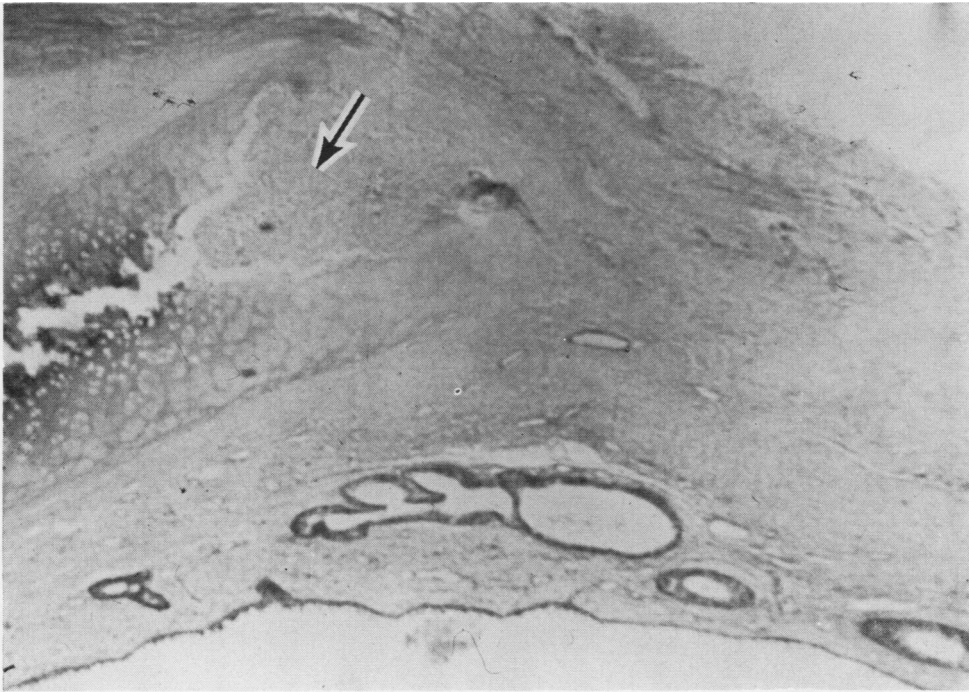


FIG. 12. A microscopic cross-section of the tracheostome of a dog of group B killed 48 days after extubation. The arrow illustrates active granulation tissue invading and replacing in varying degrees the dying or dead cartilage at the margin of the stoma. The submucosa over the adjacent living cartilage is also being replaced by fibrous tissue. This process seems still active microscopically at the time of killing and after intraluminal epithelialization has occurred. The epithelium has undergone squamous metaplasia. H. and E. $\times 15$.

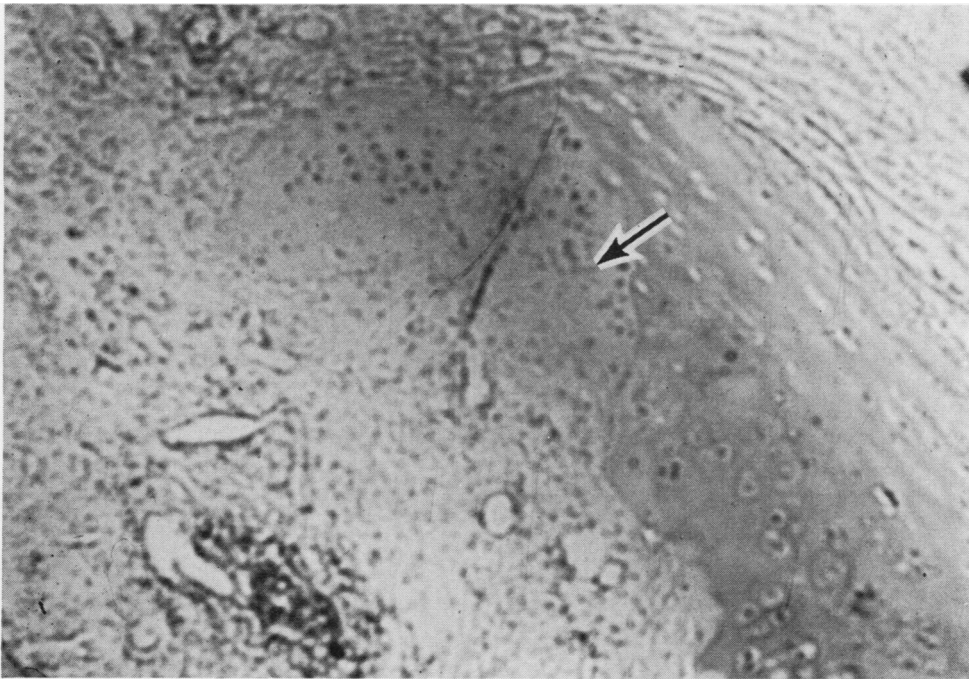


FIG. 13. A high-power microscopic cross-section of the tracheostome of the same dog as in Fig. 12. The arrow points to active proliferating granulation tissue invading the cartilage at the margin of the stoma. The cartilage is either dying or dead, as characterized by either abnormal or empty lacunae. H. and E. $\times 25$.

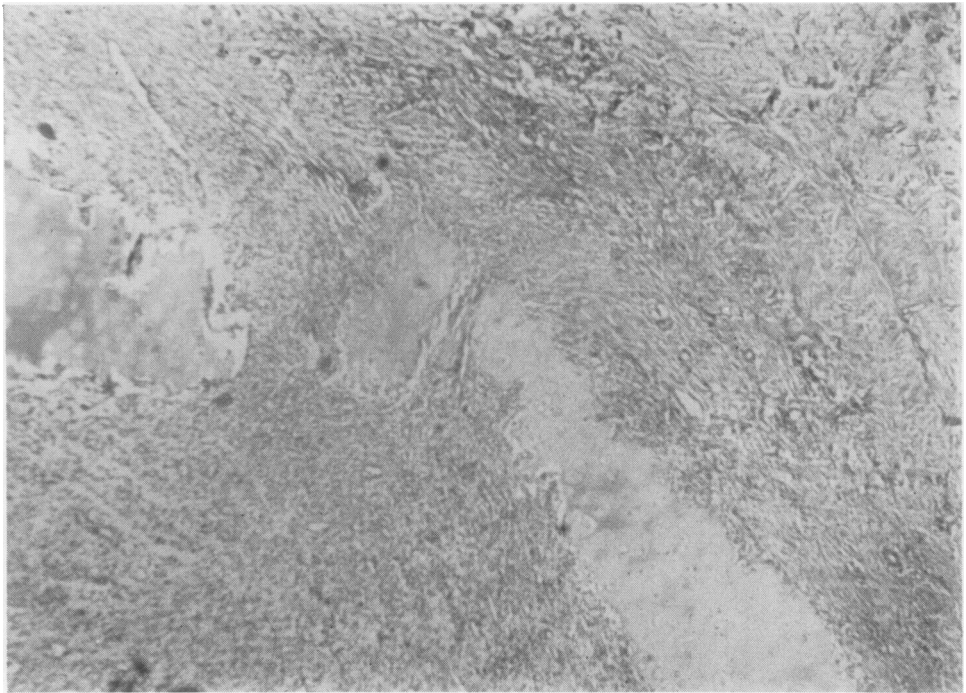


FIG. 14. *A microscopic cross-section through the trachea at the level of the tip of the cannula in a dog of group C 44 days after extubation. The cartilage is undergoing necrosis with a resultant break in the continuity of the cartilaginous ring. Active granulation tissue is replacing the adjacent dying or dead cartilage as well as the underlying submucosa. H. and E. $\times 15$.*

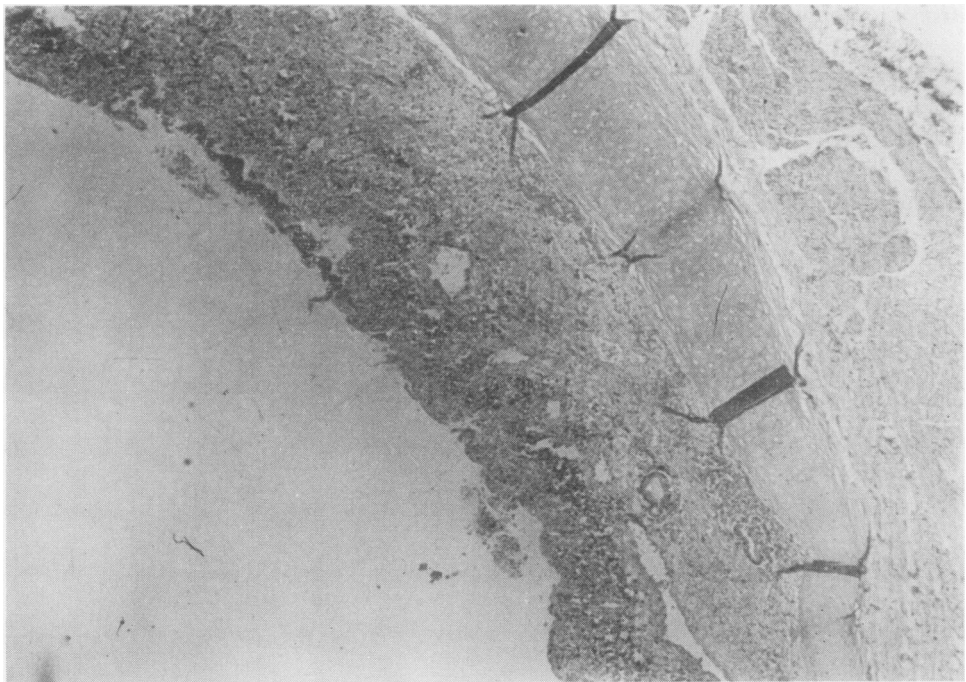


FIG. 15. *A microscopic cross-section of a trachea distal to the cuff in a dog dying of acute haemorrhagic tracheitis five days after tracheotomy. The submucosa is greatly thickened by acute inflammatory cells and contains scattered areas of microthrombi and microhaemorrhages. The mucosa is totally ulcerated and absent. H. and E. $\times 10$.*

the submucosa was greatly thickened, predominantly by acute inflammatory cells. Areas of microthrombosis and microhaemorrhage were scattered throughout the submucosa, and the mucosa was thin, ulcerated, or absent, depending upon the severity of the infection (Fig. 15). Peritracheal inflammation was common microscopically only, and in these cases it was mild. The area beneath the cuff displayed a less severe tissue response to infection than elsewhere, the cuff appearing to act as a protective barrier.

Steroids increased the damage to tissues at the stoma caused by the cannula. The adjacent cartilages were totally denuded of mucosa and submucosa and the inflammatory response was absent. Extensive haemorrhagic tracheitis was seen, especially distal to the cuff and between the cuff site and the stoma, but there was no evidence of an inflammatory infiltrate.

DISCUSSION

Of the 37 tracheotomies performed on healthy animals there were 12 survivors. The conditions in the kennels were relatively constant with only an occasional outbreak of respiratory tract infection, insufficient to explain the marked discrepancy in survivors in each of the four groups. The dogs with high cuff pressures and those with low cuff pressures and steroids were most susceptible to acute haemorrhagic tracheitis, excessive tracheal secretions, and obstruction of the cannula. Steroid therapy was associated with diffuse bronchopneumonia, resistant to the usual antibiotic coverage in four of the 10 dogs in that group.

Tracheal stenosis was produced in all survivors at the level of the tracheostome. The more severe stenoses were produced in tracheas with small diameters and in those with more than one ring incised or excised at operation. None of the three types of incisions used was preferable as far as the degree of stenosis was concerned since the H-shaped incision ultimately resulted in a window excision after the flaps of cartilage had become denuded, necrotic, and then totally absent.

No strictures were produced and no evidence of tracheal trauma was observed at the cuff level before or after extubation. There was no detectable difference in the use of either the Marrant-Baker or Rusch disposable cuffs. In eight of the 12 survivors the distal end of the cannula produced deformities of the anterior tracheal wall, five to six rings below the stoma, and in one, the cartilage underlying this area was totally eroded and invaded by active granulation tissue, thereby

producing a fibrotic stenosis. No subglottic abnormalities were seen in the study.

The stenoses were all typical wedge-shaped strictures due to the anterolateral collapse of the remaining cartilages at the stoma accompanied by fibrous contracture anteriorly at the healed stoma. The posterior membranous trachea remained intact and at times was puckered intraluminally.

Necropsy examinations on dogs dying soon after tracheotomy revealed that the inflated cuff appeared to serve as a protective barrier against the threat of severe tracheitis. Even though the area beneath the cuff had become infected, this was not as severe as the tracheitis, vascular congestion, erythema, and oedema found elsewhere. Microscopically this was also demonstrable. Pooling of secretions and exudate was most marked in the area just distal to the cuff near the tip of the cannula (Fig. 16).

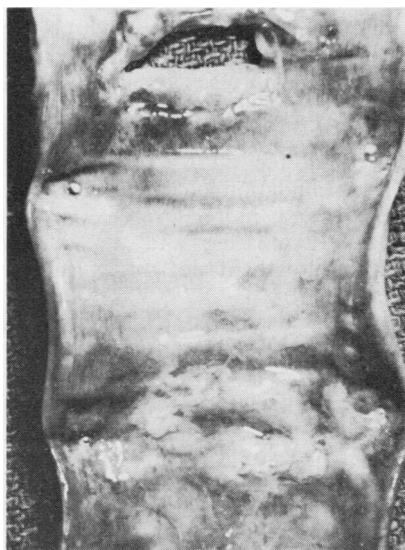


FIG. 16. The inner aspect of the trachea of a 35-lb. dog of group C, dying of a plugged cannula two days after tracheotomy. The area of trachea at cuff level appears to be protected from the vascular congestion, erythema, and oedema found elsewhere. Pooling of secretions is noted in the area just distal to the cuff about the tip of the cannula.

When dogs were killed, latex injections showed a relative deficiency of submucosal vasculature under the cuff when compared with other areas that appeared similar to the pattern seen in normal dogs. Evidently the degree of ischaemia was insufficient to produce a lesion at this level.

Florange *et al.* (1965) classified tracheal infections caused by cannulae into four microscopic stages. Stage 1 described a superficial irritation of

mucosa caused by the cannula or cuff; stage 2 affected the submucosa and perichondrial areas corresponding to the zones of contact with the cannula; stage 3 described total denudation of the cartilage with tissues between and behind the cartilage involved in an exudative inflammatory response with thrombosed peritracheal veins and lymphatics engorged with cellular debris; stage 4 described circumferential mediastinitis occurring in contact with the necrotic trachea and localized to the peritracheal area. Our findings in dogs dying with plugged tubes and acute haemorrhagic tracheitis were similar to the first three stages only and occurred very rapidly.

The defect at the stoma heals with fibrous tissue and the cartilage does not regenerate. The inner edges of the cartilages at the stoma display invasion and phagocyte-like activity by small fibroblasts, and in dogs killed up to 69 days after extubation this process remains active. Therefore the dissolution of cartilage is a chronic process, perhaps supplemented by infection, and might have produced a more severe stenosis if the dogs had been killed three to six months after extubation.

Steroids reinforce all the processes described above. The denudation of cartilage at the stoma is quickened and more severe. The infectious tracheitis is fulminating and the inflammatory responses are greatly if not totally suppressed.

SUMMARY OF MECHANISM OF ANTEROLATERAL STENOSIS

(a) Cartilage is excised from the anterior tracheal wall at tracheotomy.

(b) More cartilage dies due to loss of overlying mucosa and lack of nutrition. Ulceration is due to pressure from the tracheotomy tube probably aggravated by infection.

(c) The extent of the cartilaginous loss will clearly be related to the diameter of the tube.

(d) Studies indicate that this process is further aggravated by the addition of steroid therapy.

(e) Dead cartilage disappears and is replaced by vascular granulation tissue which becomes mature with decreasing vascularity and cellularity when the ulcerated surface is epithelialized. There may be a stage after extubation when ulceration persists and vascular inflamed granulation tissue destroys more living cartilage.

(f) Pyogenic infection of denuded cartilage occurs and tends to spread to adjacent living cartilage which may produce still more loss of cartilage wide of the stoma.

(g) As inflammation subsides and fibroblasts

produce a mature collagenous scar, scar contraction pulls the remaining ends of the cartilage rings at the margins of the defect together, forming the typical wedge-shaped defect with anterolateral stenosis.

REFERENCES

- Aboulker, P., Lissac, J., and Saint-Paul, O. (1960). De quelques accidents respiratoires dus au rétrécissement du calibre laryngo-trachéal après trachéotomie. *Acta chir. belg.*, **59**, 553.
- Adriani, J., and Phillips, M. (1957). Use of the endotracheal cuff; some data pro and con. *Anesthesiology*, **18**, 1.
- Andrews, M. J., and Pearson, F. G. (1971). Incidence and pathogenesis of tracheal injury following cuffed tube tracheostomy with assisted ventilation: analysis of a two-year prospective study. *Ann. Surg.*, **173**, 249.
- Colles, C. J. (1886). Stenosis of the trachea after tracheotomy for croup and diphtheria. *Ann. Surg.*, **3**, 499.
- Cooper, J. D., and Grillo, H. C. (1969). Experimental production and prevention of injury due to cuffed tracheal tubes. *Surg. Gynec. Obstet.*, **129**, 1235.
- Deverall, P. B. (1967). Tracheal stricture following tracheostomy. *Thorax*, **22**, 572.
- Falbe-Hansen, J. (1955). On the treatment of tracheal stenosis in tracheotomized polio patients. *Acta oto-laryng. (Stockh.)*, **45**, 498.
- Florange, W., Muller, J., and Forster, E. (1965). Morphologie de la nécrose trachéale après trachéotomie et utilisation d'une prosthèse respiratoire. *Anesth. Analg. Réanim.*, **22**, 693.
- Gibson, P. (1967). Aetiology and repair of tracheal stenosis following tracheostomy and intermittent positive pressure respiration. *Thorax*, **22**, 1.
- Johnston, J. B., Wright, J. S., and Hercus, V. (1967). Tracheal stenosis following tracheostomy: a conservative approach to treatment. *J. thorac. cardiovasc. Surg.*, **53**, 206.
- Kucher, R., Lechner, G., Pokieser, H., and Steinbereithner, K. (1967). Spätschäden der Trachea nach Tracheotomie. *Anesthetist*, **16**, 157.
- Little, D. (1956). *Controlled Hypotension in Anesthesia and Surgery*, p. 79. Thomas, Springfield, Illinois.
- Mori, S. (1932). Experimentelle Studien über die Pathologie der Trachea und Bronchien bei Trachealatumung. *Okayama-Igakkai-Zasshi*, **44**, 2295.
- (1936). Experimentelle Studien über den Heilungsvorgang nach der Exstirpation des Trachealknorpels. *Okayama-Igakkai-Zasshi*, **48**, 334.
- Murphy, D. A., MacLean, L. D., and Dobell, A. R. C. (1966). Tracheal stenosis as a complication of tracheostomy. *Ann. thorac. Surg.*, **2**, 44.
- Nelson, T. G. (1958). *Tracheotomy—A Clinical and Experimental Study*. Williams and Wilkins, Baltimore.
- Paloschi, G., and Lynn, R. B. (1965). Observations upon elective and emergency tracheostomy. *Surg. Gynec. Obstet.*, **120**, 356.
- Pearson, F. G., and Fairley, H. B. (1970). Tracheal stenosis complicating tracheostomy with cuffed tubes. *International Anesthesiology Clinics*, **8**, 889.
- , Goldberg, M., and Da Silva, A. J. (1968a). Tracheal stenosis complicating tracheostomy with cuffed tubes: clinical experience and observations from a prospective study. *Arch. Surg.*, **97**, 380.

- , —, and — (1968b). A prospective study of tracheal injury complicating tracheostomy with a cuffed tube. *Ann. Otol. (St. Louis)*, **77**, 867.
- Putney, F. J. (1955). Complications and postoperative care after tracheotomy. *Arch. Otolaryng. (Chicago)*, **62**, 272.
- Schueller, M. (1880). *Die Tracheotomie, Laryngotomie und Exstirpation des Kehlkopfes*. F. Enke, Stuttgart.
- Stiles, P. J. (1965). Tracheal lesions after tracheostomy. *Thorax*, **20**, 517.
- Teplitz, C., Epstein, B. S., Lawrence, L. R., and Moncrief, J. A. (1964). Necrotizing tracheitis induced by tracheostomy tube. *Arch. Path.*, **77**, 6.
- Thost, A. (1911). *The Stenosis of the Upper Air Passages Following Tracheotomy and Their Treatment*. J. F. Bergmann, Wiesbaden.