

THE PRESSURES EXERTED ON THE TRACHEA BY ENDOTRACHEAL INFLATABLE CUFFS

BY

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SUMMARY

The pressures exerted on the tracheal wall by cuffed endotracheal tubes were measured in patients on intermittent positive pressure ventilation. It was found that these pressures can easily be made excessive and sufficient to encourage tracheal necrosis. These pressures exerted by the cuffs were not equally distributed around the tracheal circumference and varied also with the position of the head and with the level of consciousness.

It is rare for serious complications to follow short-term endotracheal intubation. However, the introduction of longer periods of intubation for the purpose of mechanical respiratory assistance has led to a rise in the incidence of complications.

The most serious complication of the use of cuffed tubes, and the most difficult to treat, is the development of tracheal stenosis due to mucosal ulceration and cartilage destruction. Although rotational and shearing stress together with infection play a part in its aetiology, the pressure exerted on the tracheal mucosa and its duration must be the important factors.

Several studies have been made to estimate the pressure applied to the tracheal mucosa by an endotracheal cuff (cuff/tracheal pressure or C/T pressure) using rigid models or excised tracheae. The pressures varied widely: 3–8 cm H₂O (2–6 mm Hg) (Muir and Stratton, 1954); 10–15 mm Hg (Adriani and Phillips, 1957); 5–147 mm Hg (Carroll, Hedden and Safar, 1969); and equal to the positive inspiratory pressure (Lomholt, 1967). As none of these studies was made on patients it would seem important to obtain pressure measurements in patients whilst on intermittent positive pressure respiration.

METHOD

Any estimates based on recordings of the pressures within the cuffs are fallible owing to the elastic properties of the cuff which vary with temperature, age and duration of distension. Separate balloons inserted between the cuff and the tracheal wall have also been found to be impracticable in that a large balloon distorts the endotracheal cuff and a small balloon both limits the range of the recordable pressure and is prone to gross error from even a small leak.

The method described here is based on the principle of sphygmomanometry in that a "leaking" pressure is measured.

Small, flat, polyethylene envelopes were manufactured measuring approximately 2" × ¼". These were fused on to the ends of nylon pressure lines, which were then connected to a small distensible balloon reservoir and a mercury manometer and, via a three-way tap, to an inflation nipple. The distal end of the envelope remained open. The envelope was placed alongside the cuff on the endotracheal tube and secured proximally and distally (fig. 1). Care was taken to ensure that the envelopes were not under tension even when 12–14 ml of air was put in the cuff, by securing the envelope while the cuff was partially inflated. After insertion of the endotracheal tube into the patient's trachea it was possible to measure the C/T pressure by rapidly forcing air into the inflation nipple, closing the system and allowing leakage to occur from the open-ended envelope. Leakage continued until the envelope collapsed and became occluded by external pressure—the pressure exerted by the cuff on the tracheal wall. The residual pressure in the measuring system equalled the occluding pressure.

Throughout this study, latex armoured balloon cuffed endotracheal tubes were used and inspiratory positive pressures were adjusted to 20 ± 2 cm H₂O (15 ± 1.5 mm Hg). The minimum occlusive volume (MOV) (i.e. that cuff volume which is needed to produce an airtight seal between trachea and cuff) was recognized by direct auscultation over the trachea.

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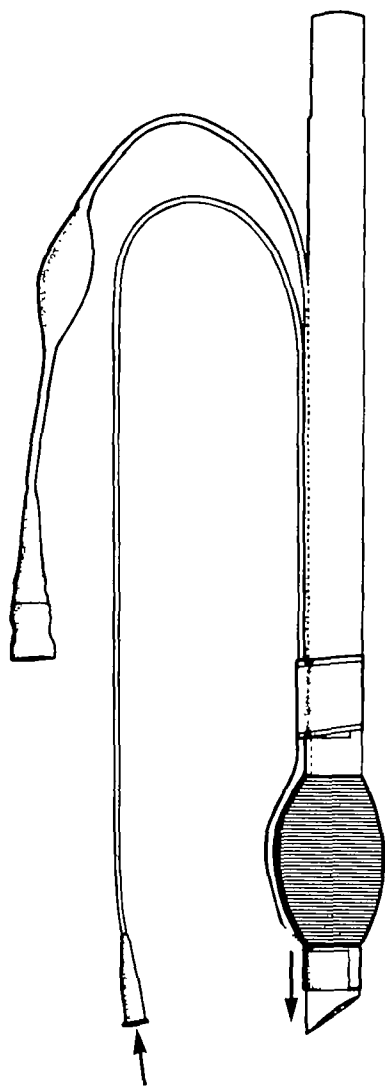


FIG. 1

Diagram showing the position of the collapsible polyethylene envelope on the anterior aspect of the inflatable cuff.

CLINICAL RESULTS

The patients investigated fall naturally into three groups:

Group I.

Eleven anaesthetized patients were intubated with the pressure-measuring envelope placed anteriorly. Cuff/tracheal pressures were measured for varying intracuff volumes and pressures. The findings of a typical case are given in table I.

It can be seen (table II and fig. 2) that the C/T pressures at MOV are normally between 25 and 45 mm Hg. With increments of cuff volume over the MOV the C/T pressures rose rapidly to very high levels.

TABLE I

Cuff/tracheal pressures, cuff pressure and cuff volumes. Case 3, female aged 20 years, undergoing operation for correction of ASD. No. 9 latex endotracheal tube used. MOV = minimum occlusive volume.

Cuff volume (ml)	Cuff pressure (mm Hg)	C/T pressure (mm Hg)
0	0	14
2	80	26
MOV 4	100	40
6	160	44
8	220	62
10	290	76
12	310	120

TABLE II

Cuff/tracheal pressure (mm Hg) with increasing volumes above minimum occlusive volume (MOV).

Case	Cuff volumes (ml)									
	0	2	4	6	8	10	12	14	16	18
1	68	110	130	166	270					
2		40	54	80	108	150	280			
3			40	44	62	76	120			
4			30	36	60	88	132	210		
5					46	66	100	200		
6					26	54	88	140		
7					24	30	46	130	250	
8						44	45	64	132	
9						28	48	98	160	
10							28	32	64	130
11							44	50	120	140

Note: The first recording, in each case, is for the MOV.

TABLE III

Anterior and posterior C/T pressure differences.

	C/T pressure (mm Hg) at MOV	
	Anterior	Posterior
Head flexed or neutral	46	44
	34	20
	48	28
	60	32
	16	12
PM specimen	32	22
PM specimen	42	28
Average	39.6	26.6

Group II.

As in Group I, but in five patients, instead of a single pressure envelope, two were applied to the endotracheal tube, one anteriorly and one

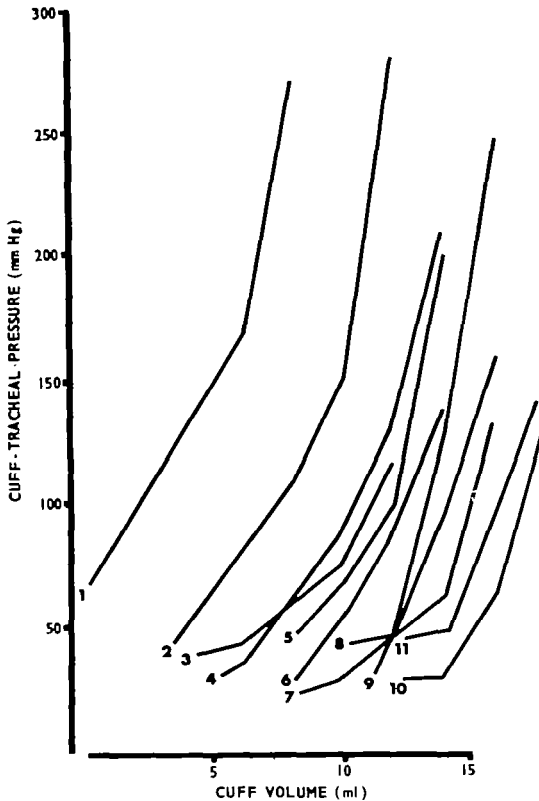


FIG. 2

Graph of change in cuff/tracheal pressure with increasing volumes above minimum occlusive volume. Eleven cases.

posteriorly. Similar recordings made on tracheae excised postmortem are included.

The pressures measured at MOV (table III) show that for normal or flexed positions of the head, the anterior pressure was up to twice as high as that exerted posteriorly. With extension of the head (three cases) the difference between anterior and posterior pressures lessened or even

TABLE IV

Alteration in anterior and posterior C/T pressures with position of the head.

C/T pressure (mm Hg)			
Head flexed		Head extended	
Anterior	Posterior	Anterior	Posterior
58	24	58	32
74	84	74	104
24	12	20	40
—	—	—	—
Average	52	40	51
			59

became reversed (table IV). At cuff volumes in excess of the MOV the two pressures rapidly became equal and rose together.

Group III.

In ten patients, the measurements were repeated before cessation of assisted respiration when the patients were conscious or semiconscious. Measurements were repeated using the same cuff MOV as when deeply anaesthetized. Initial measurements were made soon after induction and intubation, when a muscle relaxant was fully active. The second reading was made prior to extubation, in half the cases at the end of operation, on the table, and in half after 18–24 hours ventilator assistance and nitrous oxide-oxygen analgesia. The position, body supine and head neutral, was the same for both measurements.

On recovery from anaesthesia the C/T pressures increased (fig. 3). In other words, with lightening of consciousness the MOV became smaller.

DISCUSSION

The pressures exerted by the cuffs on the anterior tracheal wall at MOV were found to be mainly between 25 and 45 mm Hg. With a positive inspiratory pressure of 20 cm H₂O (15 mm Hg)

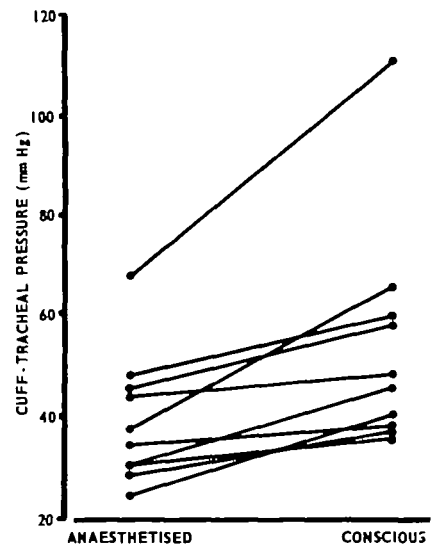


FIG. 3

Variation in cuff/tracheal pressure with recovery from anaesthesia. Cuff volume was unchanged, and was the MOV when anaesthetized. Thus the MOV is usually less on recovery.

it would be expected that the C/T pressures at MOV would equal or just exceed this, and this is the principle in the work of Lomholt (1967). Indeed it is found that this is the case when the posterior C/T pressures are also measured, the membranous posterior tracheal wall being more distensible and compliant than the anterolateral cartilaginous aspects. (That extension of the head reverses the pressure difference is no doubt due to the added support of the vertebral column to the posterior tracheal wall.) Cooper and Grillo (1969) deduced this pressure difference to explain the fact that the tracheal damage is most marked over the anterior cartilaginous part of the trachea.

The C/T pressures at the MOV are acceptably low but with any increase in cuff volume beyond that necessary these pressures rise steeply to alarming levels, and underline the importance of overcoming the temptation to "add a few cc's for safety's sake". This steep rise in pressure increases the mucosal damage and explains the incidence of stenosis found by Shelly, Dawson and May (1969) when using twice the MOV.

It is the authors' impression, from additional cases, and illustrated by Case 1 (table I and fig. 2), that the C/T pressures are highest at MOV and that the quickest and steepest rises in pressure occur when the endotracheal tubes fit tightly and small inflation volumes are required to procure occlusion. The explanation is probably that expansion of a large latex cuff only becomes even after the insertion of 2-3 ml of air. Thus the observation is indirectly in accord with the conclusion of Lomholt (1967) and Carroll, Hedden and Safar (1969).

Two further aspects require consideration when it is intended to maintain prolonged intubation for respiratory assistance. First, with flexion of the head the anterior C/T pressures will be proportionally higher; most patients when conscious are allowed to rest their heads in semiflexion. Secondly, the volume necessary for occlusion will vary with muscle tone and the state of consciousness; thus for unchanged cuff volumes higher C/T pressures will be recorded in a conscious than in an unconscious state, and this underlines the necessity of regular and frequent checking of cuff volumes whether periodic deflation is practised or not.

Cessation of capillary flow, by external pressure, will occur when that pressure exceeds the

clinically accepted 32 mm Hg of the arteriolar capillary, plus the resistance of the surrounding tissue. For the finger, Coles and Gough (1960) found this external pressure to be 32-60 mm Hg. Thus it is easy to make the pressure exerted on the trachea by an endotracheal cuff exceed the perfusion pressure, and thus predispose to mucosal ulceration and cartilaginous destruction on the anterior wall.

ACKNOWLEDGEMENT

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LA PRESSION EXERCÉE SUR LA TRACHÉE PAR DES MANCHETTES ENDOTRACHEALES GONFLABLES

SOMMAIRE

La pression, qu'exercent des tubes endotrachéaux à manchette sur la paroi de la trachée, a été mesurée chez des patients sous ventilation à pression positive intermittente. On constata que ces pressions peuvent aisément devenir excessives et suffisantes pour causer une nécrose de la trachée. Les pressions exercées par les manchettes ne sont pas régulièrement distribuées sur la circonférence de la trachée et dépendent également de la position de la tête et du niveau de conscience.

DRUCK AUF DIE TRACHEA BEIM AUFBLASEN DES ENDOTRACHEAL TUBUS

ZUSAMMENFASSUNG

Der Druck auf die Trachealwand durch den Endotrachealballon wurde bei Patienten, die intermittierend positiv beatmet wurden, gemessen. Dabei stellte sich heraus, daß es leicht zu hohen Drucken kommen kann, die ausreichen, um eine Trachealnekrase herbeizuführen. Die Drucke, die durch die Ballone ausgeübt werden, verteilen sich nicht gleichmäßig auf den Umfang der Trachea und sind ebenso von der Kopfhaltung und vom Bewußtseinsgrad abhängig.