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A Physiologic Study on Respiratory Handicap of the Laryngectomized*

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Physiologische Studie über die Beeinträchtigung der Atemfunktion beim Laryngektomierten

Zusammenfassung. Die Untersuchung der Atemfunktion bei dreizehn laryngektomierten Patienten zeigte, daß sich das Fehlen der oberen Luftwege ungünstig auf die unteren Atemwege auswirkt. Besonders auffällig war eine ungleichmäßige Verteilung der Atemluft in der Lunge.

Schlüsselwörter: Beeinträchtigung der Atemfunktion – Laryngektomierter – Pulmonale Aerodynamik – Verengung der kleinen Atemwege

Summary. Lack of the upper airway function after laryngectomy creates unfavorable effects on the lower respiratory tract. The purpose of this study is to re-evaluate this relationship objectively.

Respiratory function tests were performed on 13 laryngectomized patients. Pulmonary volumetry and ventilometry revealed increased RV and FRC, and decreased $FEV_{1.0}\%$, indicating evidence of obstructive changes in the lung. MEFV-recordings showed greater downward convexity than those of the normal at the lower volume level. The value of MEF_{50}/body-height was definitely smaller than normal average in the same age group.

Pulmonary resistance was in wide variety but definitely lower than normal because of lack of the upper airway resistance. If this component is added to the value, the total will be in normal range or even higher.

Dynamic compliance remained mostly in the normal range when measured using a mask at the tracheostoma. The value was lower than normal when measured through a cuff-canule. The difference in static and dynamic compliances was greater than that in normal cases, which may

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indicate evidence of uneven distribution of air in the lung. Regular check-up and suitable respiratory care are recommended on the laryngectomized.

Key words: Respiratory handicap – The laryngectomized – Pulmonary aerodynamics – Small airway obstruction

The upper respiratory tract plays such important roles as an air-conditioner with its warming, humidifying, and filtering abilities of inhaled air, a rheostat to control the respiratory resistance for keeping the optimal intrapulmonary gas exchange, and a protector of the lower respiratory tract with various neural reflexes. Lack of these functions after laryngectomy creates various unfavorable effects on the lower airway. Heyden (1950), Eguchi (1966), Torjussen (1968), Fukunaga (1975), and Usui (1979) studied the respiratory function in laryngectomized patients. Some of them revealed the obstructive changes of varying degrees in the lower respiratory system of the laryngectomized. The purpose of this study is to re-evaluate this relationship objectively with special emphasis on the contribution of the upper airway, especially the nose, to the whole respiratory function.

Methods and Subjects

Air-conditioning Abilities of the Upper Airways

Temperatures of breathing air at various spots were measured with thermocouple-wires through a needle. Vapor pressure in inhaled air was measured with a mass-spectrometer (Varian-Matt M3-BA). These values were recorded on an oscillograph sheet and read out.

Lung Volumes

Total lung capacity (TLC), vital capacity (VC), tidal volume (TV), functional residual capacity (FRC), residual volume (RV), percent residual volume (RV/TLC%), one-second forced expiratory volume ($FEV_{1.0}$), and $FEV_{1.0}$/VC ($FEV_{1.0}$%) were obtained by spirometry and ventilometry (CHEST OSF-II).

Maximum Expiratory Flow Volume Curve Recordings (MEFV Curve)

From the MEFV curves recorded, the values of peak expiratory flow (PEF), maximal expiratory flows measured at the points of 50% and 25% FVC ($\dot{V}_{50}$ and $\dot{V}_{25}$) were obtained (with CHEST OST-70F).

Pulmonary Mechanics

Pulmonary resistance (R_P) and compliances under dynamic and static conditions (C_{dy} and C_{st}) were measured using electronic devices (Nihon Kohden MFP-1, RM-45, WX-432).

Subjects of the study were 13 laryngectomized patients, in eight of which the measurements were performed applying a small mask directly on the tracheostoma, and in five of which the measurements were done adapting a Portex cuff-canule in the stoma, which was in turn connected to the measuring apparatus. Airway resistance of the canule with a 14 mm diameter is 0.9 cm H_2O/l/s at a flow rate of 0.4 l/s, and with an 11 mm diameter it is 2.7 cm H_2O/l/s at a rate of 0.3 l/s.

Results

Air-conditioning Abilities

As we (1977) already reported elswhere, room air at 22.5° C inhaled through the nose was warmed up to 34.1° C when measured at the tracheostoma. The air temperature inhaled through the mouth elevated to 32.9° C at the tracheostoma. The laryngectomized patients are obliged to inhale the room air of 22.5° C directly through the tracheostoma (Table 1).

The vapor pressure of 14.08 mm Hg in the room air with 52% relative humidity at 23° C which was inhalted through the nose increased to 45.85 mm Hg at the tracheostoma. This value approximated to that

Table 1. Temperature of inhaled air

	Nasal breathing	Oral breathing	Tracheal breathing
Atmosphere	22.5° C	22.5° C	22.5° C
	↓ 10.9° C (76.2%)	↓ 8.5° C (58.4%)	⋮
Oropharynx	33.4° C	31.0° C	⋮
	↓ 0.7° C (4.9%)	↓ 1.9° C (14.3%)	⋮
Trachea	34.1° C	32.9° C	22.5° C
	↓ 2.7° C (18.9%)	↓ 3.9° C (27.3%)	↓ 14.3° C (100%)
Alveoli	36.8° C	36.8° C	36.8° C
Difference	14.3° C (100%)	14.3° C (100%)	14.3° C (100%)

Table 2. Vapor pressure of inhaled air

	Nasal breathing	Oral breathing	Tracheal breathing
Atmosphere	14.1 (23° C, 52%)	14.1 mm Hg	14.1 mm Hg
	↓ 31.75 (94.9%)	↓ 29.85 (89.4%)	⋮
Trachea	45.85	43.95	14.1
	↓ 1.68 (5.1%)	↓ 3.58 (10.7%)	↓ 33.43 (100%)
Alveoli	47.53 (BTPS)	47.53	47.53
Difference	33.43 (100%)	33.43 (100%)	33.43 100%)

Table 3. Results of pulmonary volumetry and ventilometry in the laryngectomized

No.	Name	Age	Sex	Ht	Surg.	Postop.	VC	VC%	FV_1	FV_1%	TLC	FRC	RV	RV%	TV	Remarks
1	S. K.	60	M	153	Total	3 mo	3.40	(105.0)	1.72	(50.5)	7.72	5.26	4.32	(56.0)	0.8	Trach. mask
2	S. Y.	64	M	164	Total	7 mo	3.20	(95.0)	1.86	(58.1)	7.55	5.72	4.35	(57.6)	0.5	
3	O. M.	58	M	155	Total	7 mo	4.00	(117.0)	2.50	(62.5)	6.35	4.29	2.39	(37.6)	0.4	
4	N. S.	50	M	165	Hemi	10 mo	3.50	(97.0)			6.70	4.20	3.20	(47.8)	0.25	
5	S. T.	68	M	155	Total	1 yr 0 mo	2.70	(86.0)			6.41	4.97	3.70	(57.7)	0.45	
4′	N. S.	52	M	162	Total	1 yr 1 mo	3.74	(102.9)	2.97	(79.5)	5.76	3.80	2.02	(35.0)	0.4	
6	K. J.	66	M	168	Hemi	2 yr 1 mo	3.00	(88.0)			8.81	7.00	5.80	(66.0)	0.45	
7	H. T.	52	M	158	Total	4 yr 0 mo	3.68	(110.0)			6.50	4.30	2.82	(43.4)	0.4	
8	T. K.	56	M	155	Total	5 yr 8 mo	2.38	(69.6)	1.50	(63.0)	6.00	4.30	3.61	(60.2)	0.65	
9	H. T.	58	M	159	Total	1 yr 0 mo	3.25	(96.0)			7.20	4.58	3.95	(54.9)	0.6	Canul. No. 14
10	K. C.	70	M	166	Total	2 yr 1 mo	1.60	(49.4)	1.02	(63.8)	7.16	6.07	5.56	(77.7)	0.3	No. 11
11	N. S.	56	M	152	Total	2 yr 2 mo	2.50	(75.9)	1.54	(61.6)	7.20	5.60	4.70	(65.3)	0.8	No. 14
12	O. S.	58	M	161	Total	2 yr 10 mo	3.45	(100.5)	2.15	(62.5)	6.70	4.28	3.25	(48.5)	0.4	No. 14
13	H. K.	60	F	146	Total	5 yr 0 mo	2.60	(103.0)	1.70	(67.3)	6.20	4.60	3.60	(58.1)	0.4	No. 11

(47.53 mm Hg) at the body temperature, saturated with water vapor (BTPS). Even in oral breathing, the value of vapor pressure increased to 43.95 mm Hg (Table 2).

In the laryngectomized who lost such air-conditioning abilities of the upper airway, the lower airway have to provide such heat and moisture for the inhaled air. It is undoubted that breathing under such unfavorable conditions may affect the respiratory function in varying degrees.

Pulmonary Volumetry and Ventilometry

The test results (Table 3) revealed various changes in the lower airway as follows; residual volume (RV), and functional residual capacity (FRC) increased markedly beyond the normal limit in all cases except one, indicating evidence of emphysematous change in the lungs. Percent vital capacity (VC%) remained in the normal range in ten cases, but three cases were less than 80%. The values of percent one second forced expiratory volume ($FEV_{1.0}$%) decreased to less than 70% which is the lower limit of normal value in eight of nine cases.

Figure 1 showing the relationship between VC% and $FEV_{1.0}$% revealed that five of nine cases fell in the area indicating evidence of obstructive changes in the lower respiratory system, and three cases fell in the area indicating mixed changes, obstructive and restrictive.

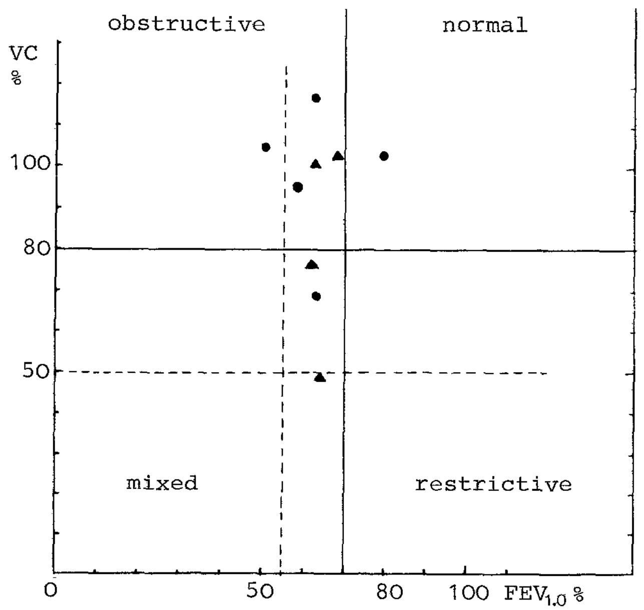


Fig. 1. Relationship between percent vital capacity (VC%) and percent one second forced expiratory volume ($FEV_{1.0}$%), showing the type of ventilatory disturbance in the lung

Table 4. Results of maximal expiratory flow volume recordings in the laryngectomized

No.	Name	Age	Sex	Ht	Surg.	Postop.	PF	$\dot{V}_{50}$	$\dot{V}_{50}$/H	$\dot{V}_{25}$	$\dot{V}_{25}$/H	$\dot{V}_{50}/\dot{V}_{25}$	Remarks
1	S. K.	60	M	153	Total	3 mo	2.4	2.0	1.31	0.5	0.33	1.20	Trach. mask.
2	S. Y.	64	M	164	Total	7 mo	6.2	1.8	1.17	0.5	0.32	3.60	
3	O. M.	58	M	155	Total	7 mo	7.5	2.3	1.45	0.6	0.38	3.80	
4	N. S.	52	M	162	Total	1 yr 1 mo	7.4	4.8	2.96	1.0	0.62	4.80	
8	T. K.	56	M	155	Total	5 yr 8 mo	3.7	0.7	0.45	0.2	0.13	3.50	
10	K. C.	70	M	166	Total	10 mo	1.8	0.4	0.24	0.2	0.12	2.00	Canul. No. 11
11	N. S.	56	M	159	Total	2 yr 2 mo	3.6	3.2	2.10	0.6	0.35	5.35	No. 14
12	O. S.	58	M	161	Total	2 yr 10 mo	4.5	3.4	2.11	0.8	0.49	4.25	No. 14
13	K. K.	60	F	146	Total	5 yr 0 mo	3.6	3.2	2.33	0.7	0.48	4.57	No. 11

Table 5. Results of pulmonary mechanics measurements in the laryngectomized

No.	Name	Age	Sex	Ht	Surg.	Postop.	R_{pl}	C_{st}	C_{dy}	Cdy/C_{st}	FRC	Cst/FRC	Remarks
1	S. K.	60	M	153	Total	3 mo	0.76	0.256	0.244	95.3%	5.26	0.049	Trach. mask.
2	S. Y.	64	M	164	Total	7 mo	1.25	0.260	0.210	80.8%	5.72	0.045	
5	S. T.	68	M	155	Total	1 yr 0 mo	1.50	0.270	0.150	55.6%	4.97	0.054	
4′	N. S.	52	M	162	Total	1 yr 1 mo	0.85	0.270	0.241	89.3%	4.20	0.064	
6	K. J.	66	M	168	Hemi	2 yr 1 mo	0.50	0.480	0.260	54.2%	7.00	0.069	
7	H. T.	52	M	158	Total	4 yr 0 mo	0.60	0.253	0.163	64.4%	4.30	0.059	
8	T. K.	56	M	155	Total	5 yr 8 mo	1.56	0.304	0.240	78.9%	4.35	0.068	
4	N. S.	50	M	165	Hemi	10 mo	1.61	0.209	0.170	81.3%	4.20	0.050	Canul. No. 11
9	H. T.	58	M	159	Total	1 yr 0 mo	0.90	0.272	0.143	52.6%	4.57	0.060	No. 14
5	S. T.	68	M	155	Total	1 yr 0 mo	1.90	0.270	0.110	40.7%	4.97	0.054	No. 14
10	K. C.	70	M	166	Total	2 yr 1 mo	4.00	0.186	0.148	79.6%	6.07	0.031	No. 11
13	O. S.	58	M	161	Total	2 yr 10 mo	2.72	0.205	0.110	53.7%	4.28	0.048	No. 14

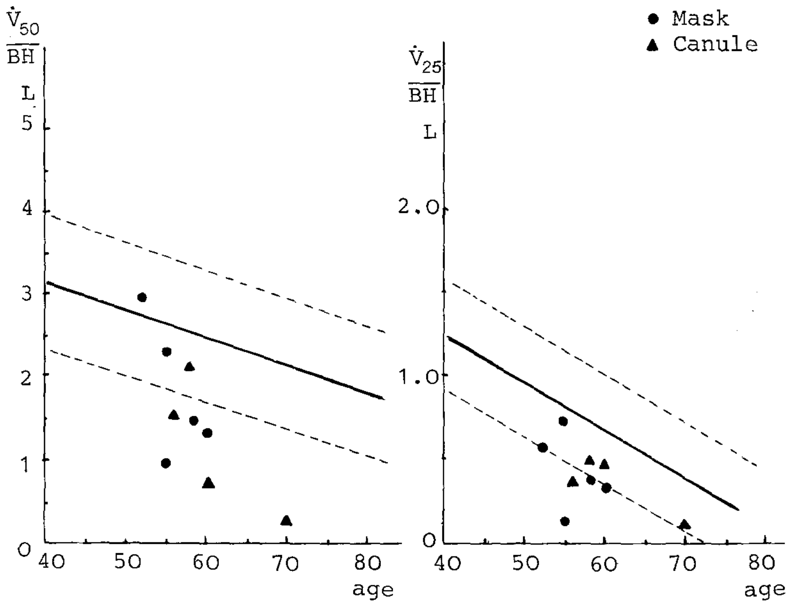
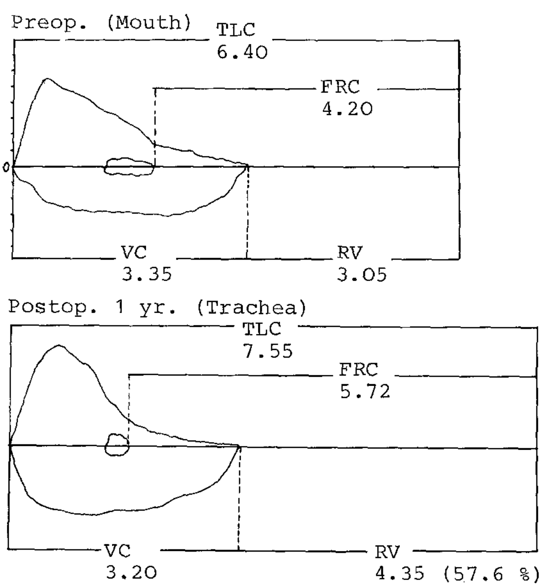


Fig. 2. Maximum expiratory flow (MEF) in the laryngectomized. The values of MEF at the 50% VC level and the 25% VC level over body height ($\dot{V}_{50}$/BH, $\dot{V}_{25}$/BH) were smaller than the normal averages



SŌYAMA 74 yr. male

BH. 154 BW. 58	Preop. Mouth	Postop. Trachea
TLC	6.40	7.55
VC	3.35	3.20
$FEV_{1.0}$	2.52	1.86
$FEV_{1.0}$%	74.80	58.10
FRC	4.20	5.72
RV	3.05	4.35
RV%	47.70	57.60
TV	0.80	0.40
PF	5.50	6.20
$\dot{V}_{50}$	2.60	1.80
$\dot{V}_{25}$	0.90	0.50
$\dot{V}_{10}$		
$\dot{V}_{50/25}$	2.90	3.60
RR	3.90	3.90

Fig. 3. Comparison of respiratory function measured before and after laryngectomy; a case of a 74-year-old man who suffered from laryngeal cancer

Maximum Expiratory Flow Volume Curve Recordings

MEFV curves in the laryngectomized showed greater downward convexity than those in normal at the lower volume level as represented with $\dot{V}_{50}$ (Table 4). In a few cases, the curves showed typical emphysematous pattern. When the cuff-canule was used for the measurement, MEF lessened because of the additional airway resistance at the tracheostoma so that the form of MEFV curve flattened. The values of $\dot{V}_{50}$ over body height and those of $\dot{V}_{25}$ over body height were smaller than normal average (Fig. 2). The MEFV curves recorded before and after laryngectomy were compared in two cases. Preoperative recordings were performed through the mouth. Figure 3 shows the case of a 74-year-old man. After surgery, downward convexity of the curve at the lower volume level was more prominent. The FRC level was also elevated.

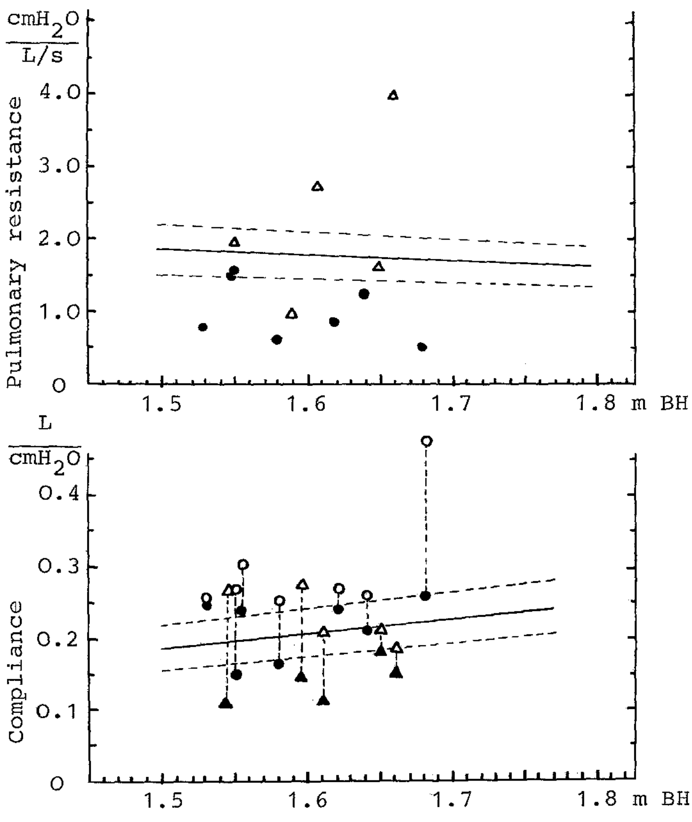


Fig. 4. Pulmonary mechanics in the laryngectomized. **a** Upper half; pulmonary resistance in relation to body height. ●: the value measured with a mask at the tracheostoma; △: the value measured through a tracheal canule. **b** Lower half; compliances in relation to body height. Static compliance (C_{st}) is represented by open marks and dynamic compliance (C_{dy}) is shown by filled marks. Circles (○,●) represent the values measured with a mask at the tracheostoma. Triangles (△,▲) represent the values measured through a tracheal canule

Pulmonary Mechanics (Table 5)

The values of pulmonary resistance were definitely smaller than normal when measured using a mask at the tracheostoma because of lack of the upper airway which occupies about a half of total airway resistance (R_{na} 0.8–1.5 cm H_2O/l/s and R_{lxa} 0.3–0.5 cm H_2O/l/s). If these components are added to the values, the total will be in the normal range or even higher. When the cuff-canule is used for measurement, the net values of R_p (acutally measured $R_p - R_{cuff}$) is in the normal range or higher than the upper limit except in one case, which proves the increase in the lower airway resistance. This may be attributable to reflective narrowing of the lower airways due to mechanical irritation of the tracheal mucose by the canule and to secretions increased secondarily (Fig. 4a).

	Nasal breathing	Oral breathing	Tracheal breathing
Air-conditioning			
Warming	o	↓	↓
Humidifying	o	↓	↓
Lung volumes			
TLC	o	o	↑
VC	o	o	↓
FRC	o	↑	↑
RV, RV%	o	↑	↑
CV%	o	o	↑
Dynamic volumes			
$FEV_{1.0}$	↓	o	↓
$FEV_{1.0}$ %	↓	o	↓
MEFV			
PEF	↓	o	↓
$\dot{V}_{50}$	↓	o	↓
$\dot{V}_{25}$	↓	o	↓
Pulm. mechanics			
R_r	o	↓	↓ OR ↑
R_p	o	↓	↓ OR ↑
C_{dy}	o	↓	↓
C_{st}	o	↑ OR ↓	↑

Fig. 5. Schematic summary of the change in parameters of respiratory function after laryngectomy from the optimal state. The arrows pointing upward indicate increase in the values and vice versa

Dynamic compliance, when measured with a mask at the tracheostoma, remained mostly in the normal range or on the borderline. When measured through a cuff-canule, the values were low out of normal range (Fig. 4b).

Static compliance showed of high values beyond the normal range in nine of 12 cases. In the other three cases the values were normal. The difference in the values of static and dynamic compliances was greater than that in normal cases, which proves the uneven distribution of air in the lung.

Discussion

It is evident that lack of the upper airway function creates unfavorable effects on the lower respiratory tract in varying degrees as demonstrated here and by the results of other investigators (Heyden 1950; Eguchi 1966; Torjussen 1968; Fukunaga 1975; Usui 1979). These changes in respiratory function are summarized schematically in Fig. 5. The arrows pointing upward indicate increase in the values, and vice versa.

Looking from the view point of aerodynamics, if the upper airway is lost so that respiration must be performed through the tracheostoma, location of the point where the pressure in the pleural cavity and that in the intrathoracic airway is balanced (equal pressure point, Mead 1967) shifts toward more peripheral,

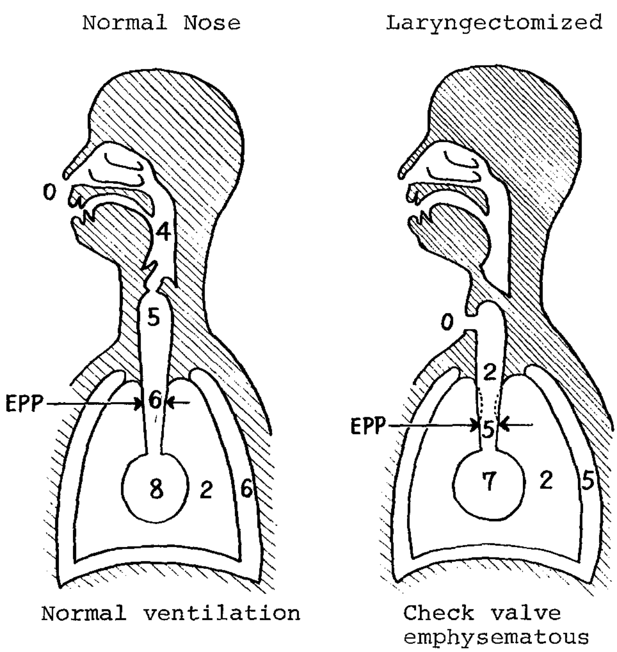


Fig. 6. Diagram showing the relation of the pressures in the pleural cavity and in the airway, especially the "equal pressure point". In case of the laryngectomized, the pressure gradient between the alveoli and the tracheostoma decreases, and the equal pressure point (EPP) shifts toward more peripheral, smaller airway region

smaller airway region, where the airway has less elasticity and is more easily flattened (Fig. 6).

Excessively low value in airway resistance and poor air-conditioning abilities after laryngectomy demand more contribution to air-conditioning (Heyden 1949; Konno 1977) and aerodynamic function (Eguchi 1966; Torjussen 1968) from the tracheo-bronchial airways.

Hypersecretion of the tracheal gland, narrowing of the tracheostoma or tracheo-bronchial cross-sectional area, modified breathing pattern which is shallower and slower than that in normal, and elevation of FRC level may help, to a certain extent, to keep intrapulmonary gas exchange normal. These abnormal conditions create and develop, through their long-standing existence, not only desiccative and chronic inflammatory changes on the tracheo-bronchial mucosa (Toremalm 1961; Fonkalsrund 1975), but also obstructive changes mainly at the segmental level of peripheral bronchioli (Eguchi 1966; Torjussen 1968; Usui 1977), organic and/or functional, especially at the proximal portion from the equal pressure point by so-called check-valve mechanism with air-trapping phenomenon. This is represented by increased RV, CV and decreased $FEV_{1.0}\%$ of spirometry, by decreased $\dot{V}_{50}$ and $\dot{V}_{25}$ of MEFV-curve recordings, and greater difference between C_{st} and C_{dy}. These changes developed in the lower respiratory tract lead to chronic ventilatory disturbance and even to emphysema. The laryngectomized should have regular check-ups followed by suitable respiratory care.

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