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Pulmonary permeability in primary ciliary dyskinesia

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ABSTRACT: Pulmonary clearance (Pcl) of aerosolized ^{99m}Tc-DTPA was studied in fourteen patients with primary ciliary dyskinesia (PCD), (median age 23.5 yrs, range 12–44 yrs) and nine normal individuals (median age 23 yrs, range 18–27 yrs). All had never smoked. Regional Pcl was studied for arbitrarily defined central and peripheral regions of the lung using a gamma camera method, whilst total Pcl was studied by a plasma sample method. The patients with PCD had significantly reduced total Pcl compared to the normal individuals ($p<0.05$) and also significantly lower total lung capacity (TLC), vital capacity (VC), forced expiratory volume in one second (FEV_1), and FEV_1/VC values ($p<0.05$). There was no correlation between Pcl and FEV_1/VC. It is concluded that the reduced Pcl in the PCD patients may be associated with their small lung volumes. In addition, reduced bronchial clearance of surfactant in PCD may be associated with an increased alveolar lining fluid volume and/or an impaired movement of ^{99m}Tc-DTPA along the alveolar septa to the bronchoalveolar junction, where the epithelium may be more specialized for absorption.
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Since 1977 [1] it has been customary to assess pulmonary permeability by measuring pulmonary clearance rate (Pcl) of inhaled nebulized ^{99m}Tc-DTPA (diethylene-triamine-penta-acetic acid). Recently it has been suggested that the surfactant lining of the alveoli is of importance for maintaining an intact epithelial permeability [2]. In the transition between the airways and the alveoli there is a functional continuity between the mucous layer of the airways and the surfactant lining of the alveoli. In normal individuals a substantial part of the alveolar surfactant is removed via the airways by mucociliary clearance. In patients with primary ciliary dyskinesia (PCD) the primary pulmonary defect is exclusively located to ciliated airways [3]. Any parenchymal involvement in these patients is, therefore, likely to be closely related to the diseased mucociliary clearance.

The aim of this study was to examine pulmonary parenchymal involvement in PCD as measured by Pcl of ^{99m}Tc-DTPA. Therefore, we compared Pcl of fourteen patients with PCD with that of nine normals. The results were related to the presence of obstructive and restrictive lung disease as evidenced by conventional spirometry and the pattern of ventilation as measured by ^{99m}Tc-DTPA ventilation scintigraphy. Pulmonary permeability was measured by two methods: 1) a plasma sample method [4] that estimates an average Pcl for all the ^{99m}Tc-DTPA that is accessible to pulmonary clearance; and 2) a gamma camera method that estimates regional and whole lung clearance from the initial slope of the detected decline in radioactivity, thereby predominantly providing information about the Pcl of the ^{99m}Tc-DTPA that is accessible to immediate transport across the alveolar-capillary barrier.

Individuals and methods

Fourteen patients with primary ciliary dyskinesia (median age 23.5 yrs, range 12–44 yrs), and nine normal individuals (median age 23.0 yrs, range 18–27 yrs) participated in the study. None of the individuals had ever smoked. Informed consent was obtained in each case and if younger than 18 yrs, from their parents also. The diagnosis of PCD was based on history, a saccharine clearance test of the nose [5], and *in vitro* microphoto-oscillographic measurement of motility of nasal cilia [6] and transmission electron microscopy of the cilia [7]. The study was approved by the local Ethical Committee.

Lung volume, flow variables and diffusion capacity

Spirometry was performed with computerized Jaeger equipment (Transferscreen®). The forced expiratory volume in one second (FEV_1), peak expiratory flow rate (PEF), and maximum expiratory flow rate at 50% of the forced vital capacity (MEF_{50}) were read from the largest of three flow-volume curves. Vital capacity (VC)

was measured as the inspiratory vital capacity, the largest of three attempts being used. Total lung capacity (TLC) was measured by a single-breath helium-dilution method. Residual volume (RV) was calculated as RV=TLC-VC. Diffusion capacity was measured as the transfer factor of the lungs for carbon monoxide (T_{LCO}) by a single-breath method [8]. The results were calculated for predicted values for adults [8] or for children if the individual was younger than 18 yrs old [3].

Determination of pulmonary clearance of ^{99m}Tc-DTPA

Preparation of ^{99m}Tc-DTPA. Sodium pertechnetate ($^{99m}TcO_4^-$) was eluted in isotonic saline from a ^{99}Mo/^{99m}Tc generator (IRE). The ^{99m}Tc was chelated to DTPA (DuPont) introducing 700 MBq $^{99m}TcO_4^-$ into a kit containing 10 mg of DTPA in a maximum volume of 5 ml isotonic saline. The ^{99m}Tc-DTPA (molecular weight 492 daltons) was made 1 h before use and stored in a nitrogen atmosphere. The binding of ^{99m}Tc-DTPA was found to be >97% complete by chromatography, where the separation of ^{99m}Tc-DTPA and $^{99m}TcO_4^-$ was achieved with acetone on alufoil cellulose. The subsequent ultrasonic nebulization did not cause chemical breakdown of the ^{99m}Tc-DTPA.

Aerosol generation and administration. The aerosol was generated in an ultrasound nebulizer (DeVilbiss 35B) containing the 700 MBq ^{99m}Tc-DTPA. It was inhaled from the nebulizer and on its way to the mouth it passed a 10 *l* container and a 1 m long hose to permit settling of larger droplets. At the mouth the aerosol particles had a mass diameter of 0.5–2.1 μm (98% <1.5 μm). A T-valve ensured that the expired air could be collected in a trap. Individuals inhaled the aerosol at slightly deeper inspirations than tidal volume. Each inspiration was slow and was followed by a 3 s pause (breath held) before expiration. The inhalation was made with the subject in the sitting position. The aerosol was administered for a maximum of 3 min, yielding a maximum count-rate of 120,000 counts per min over the entire lung field. The background count-rate was 500–1000 counts per min.

Determination of Pcl of ^{99m}Tc-DTPA by the gamma camera method

Data acquisition. Immediately after inhalation of the aerosol, the patient was seated, with back against an Anger-type scintillation gamma camera (LFOV, Searle Radiographic Inc.) having a standard field-of-view size crystal and a parallel 140 KeV collimator. Dynamic acquisition of the detected lung field radioactivity was made for 10 min on a computer (MED II, Nuclear Data). The acquisition was framed at 20 s intervals. During the acquisition, ventilation scintigrams were made on Polaroid films.

Data processing. The acquired data were processed to display initial distribution of the activity of ^{99m}Tc-DTPA. Regions of interest were created by fitting a rectangle form as closely as possible over the lung. The rectangles were divided into 3x6 units (fig. 1) and used to arbitrarily define the lung as being composed of a central and lateral part. Initial central and peripheral deposition of the activity was calculated (%) by pooling the initial count-rate of the respective parts of the two lungs.

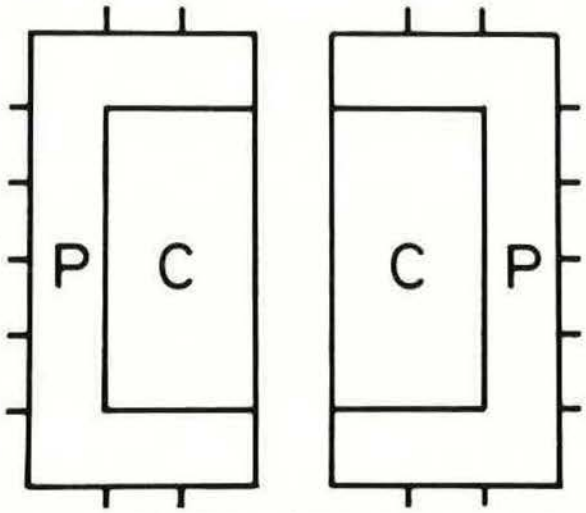

Fig. 1. – Regions which were analysed by the external detection method. C: central parts; P: peripheral parts.

To determine Pcl, a monoexponential fit was applied to the time-activity curve for the whole lung and for the central and peripheral parts separately. The background and the physical decay of ^{99m}Tc were corrected for. Pcl was described by the time constant of the monoexponential function (K), which is a commonly used index for presentation of the results of the method. The reciprocal value, 1/K, however, is the mean transit time for the transport of ^{99m}Tc-DTPA across the alveolar capillary membrane, as estimated from the ^{99m}Tc-DTPA that was accessible for transport during the first 10 min after the inhalation. It provided the mathematical basis for comparing the results of the plasma sample method and the gamma camera method.

Determination of Pcl by the plasma sample method

General procedure. At 30 min after the end of inhalation, a bolus injection of a weighed amount of 3 MBq ^{51}Cr-EDTA (ethylene diamine tetra-acetic acid) was injected intravenously. Standards were produced.

Five ml plasma samples were drawn from an indwelling needle before and 5, 10, 15, 20, 25, 30, 40, 50, 60, 90, 120, 150, 180, 200, 220 and 240 min after the end of inhalation. The radioactivity in plasma samples was used to determine the plasma time activity curve for ^{99m}Tc-DTPA following the inhalation (C(t)DTPA) and for ^{51}Cr-EDTA following the *i.v.* injection (C(t)EDTA.

Samples were counted in a well-scintillator for the

two gamma energies separately. Standard counting error: 1.00%.

Calculations. A two compartment model was applied [4] to calculate Pcl from all the ^{99m}Tc-DTPA that was accessible for transport across the alveolar capillary membrane. The model uses the fact that the mean transit time ($\bar{t}$) for compartments in series is the sum of the $\bar{t}$ for the transport through each of the compartments [11].

Mean transit time for the transport of ^{99m}Tc-DTPA through the lungs ($\bar{t}$(L)) was calculated as:

$$\bar{t}\,(L) = \bar{t}\,(L+ECV)\ DTPA\text{-}\bar{t}\,(ECV)\ EDTA$$

where the $\bar{t}$(L+ECV) is the $\bar{t}$ for the transport of ^{99m}Tc-DTPA from the lungs *via* the extracellular volume (ECV) to the kidney, which is the only organ of elimination, and $\bar{t}$(ECV)EDTA is the $\bar{t}$ for the transport of ^{51}Cr-EDTA through the ECV to the kidney. $\bar{t}$(L+ECV)DTPA and $\bar{t}$(ECV)EDTA werecalculated from C(t)DTPA and C(t)EDTA from the general formula:

$$\bar{t} = \int tC(t)dt / \int C(t)dt$$

where C(t) is the t-a curve for the tracer in question.

^{51}Cr-EDTA plasma clearance was calculated from C(t)EDTA as an index of glomerular filtration rate according to the two compartment mamillary model of SAPIRSTEIN *et al.* [12].

The ^{51}Cr-EDTA distribution space is an index of ECV and was calculated from C(t)EDTA from the same two compartment model of Sapirstein.

Statistical analysis. Results were compared by means of Student's t test for paired and unpaired data.

Results

The PCD patients had systematically lower TCL, VC, FEV_1 and FEV_1/VC values (% predicted) than the normal individuals ($p<0.05$, table 1). Four of the patients with PCD (nos. 1, 2, 7 and 14) had slight to moderate obstructive lung disease (FEV_1/FVC <75%),

Table 1. – Results of the measurements of lung volumes and diffusing capacity

Normal individuals	TLC		RV		VC		FEV_1		TLCO		RV/TLC	FEV_1/VC
	l	%pred	*l*	%pred	*l*	%pred	*l*	%pred	mmol·s^{-1}·kPa^{-1}	%pred	%	%
1	6.85	109	1.39	99	5.46	113	4.10	95	0.195	103	20	75
2	7.16	94	1.99	114	5.17	89	4.40	86	0.199	87	28	85
3	9.05	122	3.58	207	5.47	99	4.60	95	0.189	87	40	84
4	6.20	126	2.00	137	4.20	120	3.10	97	0.148	106	32	74
5	5.80	113	2.04	139	3.76	102	3.50	105	0.131	89	35	93
6	6.85	98	1.39	84	5.46	107	4.10	92	0.195	98	20	75
7	8.59	110	2.52	132	6.07	108	5.30	110	0.200	91	29	87
8	6.76	104	1.64	109	5.12	106	4.40	103	0.202	107	24	86
9	7.36	103	2.13	107	5.23	85	4.70	88	0.208	85	29	89
$\bar{x}$	7.18	108	2.08	125	5.10	103	4.24	97	0.185	95	7	83
SD	1.05	10	0.67	36	0.70	11	0.65	8	0.027	9		7
PCD Patients												
1	4.16	92	0.95	79	3.18	96	2.00	65	0.137	104	24	63
2	5.52	94	1.69	112	3.83	94	2.10	62	0.135	89	31	55
3	4.06	98	1.00	96	3.06	91	2.20	71	0.145	108	25	72
4	5.39	107	1.26	116	4.13	104	3.30	94	0.139	92	23	80
5	3.68	65	1.54	87	2.14	59	0.75	24	0.095	66	42	36
6	4.37	88	1.44	152	2.93	75	1.55	48	0.159	154	33	53
7	7.69	99	1.98	110	5.71	97	3.90	76	0.250	107	26	68
8	2.86	84	0.80	114	2.02	72	1.80	78	0.077	73	28	89
9	5.85	101	1.40	102	4.45	113	3.25	94	0.153	97	24	73
10	3.63	82	1.24	131	2.39	68	1.50	49	0.106	78	34	63
11	4.23	89	1.24	91	2.99	72	1.40	47	0.121	92	29	47
12	3.69	83	1.10	116	2.59	74	2.05	66	0.112	83	30	79
13	4.45	90	1.41	99	3.04	87	2.45	79	0.123	89	32	81
14	4.35	94	1.12	83	3.23	101	1.90	66	0.131	104	26	59
$\bar{x}$	4.57	90	1.30	106	3.26	86	2.15	66	0.135	95	29	66
SD	1.21	10	0.31	20	0.99	16	0.84	19	0.040	21	5	15

TLC: Total lung capacity; RV: residual volume; VC: vital capacity; FEV_1: forced expiratory volume in one second; TLCO: transfer factor of lungs for carbon monoxide; PCD: primary ciliary dyskinesia.

two (nos. 8 and 12) had a restrictive disease (TLC or VC <75% predicted) whilst four (nos. 5, 6, 10 and 11) had signs of combined disease. One of the patients (no. 5) also had reduced values [9] of the transfer factor. The individuals of the control group had normal spirometry and diffusing capacity.

All normal individuals, but only three of the PCD patients (nos. 4, 7 and 8) had normal ventilation scintigrams (fig. 2), *i.e.*, there were no ventilation defects and the distribution of the retained radioactivity was homogenous. Six of the patients (nos. 1, 2, 3, 9, 12 and 13) had slightly irregular distribution. Two of these (nos. 1 and 12) also had ventilation defects. Four of the patients (nos. 5, 6, 10 and 11) had severe irregular distribution with a spotty appearance and several ventilation defects. These were the patients that also had a combined restrictive and obstructive lung disease.

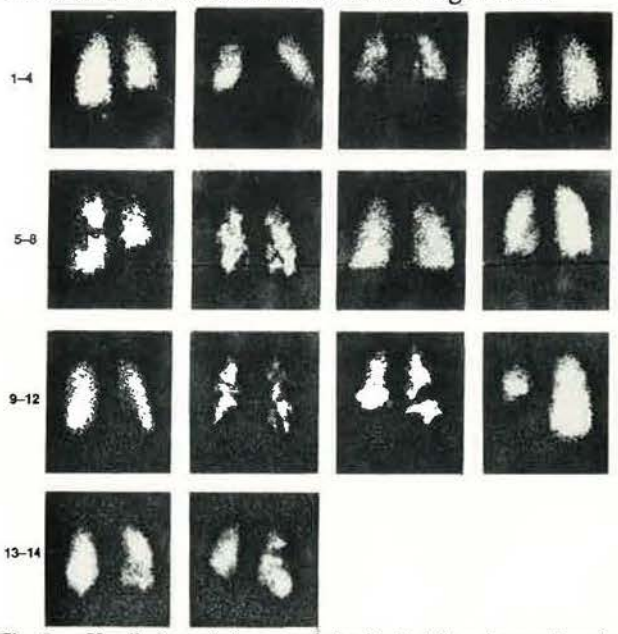

Fig. 2. – Ventilation scintigrams of the 14 (1–14) patients with primary ciliary dyskinesia.

The results of the quantitative analysis of the aerosol deposition in the lungs are given in table 2. The amount of central deposition of the aerosol was greater in the patients with PCD than in the controls ($p<0.05$). In both groups, ^{99m}Tc-DTPA tended to be cleared faster from the peripheral parts of the lungs, than from the central parts, but it was only within the group of normal individuals that significance was reached ($p<0.05$).

The results of the overall Pcl as measured by the plasma sample method are shown in table 3. The presumptions for using the plasma sample method were considered fulfilled, since all of the individuals in the study appeared to be clinically in a steady state and without oedema. Moreover, none of the individuals had excessively large ECV volumes as evidenced by the distribution space of ^{51}Cr-EDTA. Surprisingly, one of the patients with PCD (the oldest, patient no. 2) had reduced ^{51}Cr-EDTA clearance value, probably due to previous treatments with gentamicin.

The results of the plasma sample method showed that the pulmonary epithelial permeability was significantly smaller ($p<0.05$) in the PCD group than in the group of controls. The results of determining Pcl by the plasma sample method provide information about the mean transit time for all the ^{99m}Tc-DTPA that was accessible for transport across the alveolar capillary membrane. This was in line with the trend of the Pcl (whole lung, table 2), as calculated by the external detection method, which provides information about the ^{99m}Tc-DTPA that was accessible for immediate transport.

In figures 3 and 4, the values for individual transport time, $\bar{t}(L)$, have been compared to the FEV_1/FVC and T_{LCO} values, respectively. In none of the groups, however, was the pulmonary permeability significantly correlated to the presence of airflow limitation or decreased diffusion capacity.

Table 2. – Results of the quantitative analyses of the deposition of the ^{99m}Tc-DTPA aerosols in regions of interest and of the determination of Pcl by the external detection methods

	Aerosol deposition %		K-values x 10^3 min^{-1}		
	Peripheral part (P)	Central part (C)	Whole lung	Peripheral part (P)	Central part (C)
Normal individuals	40.3 (±8.6)	59.7 (±8.6)	8.4 (±3.4)	9.7 (±4.1)	7.4 (±3.6)
PCD patients	27.5 (±5.5)	72.5 (±5.5)	6.2 (±3.3)	7.6 (±4.1)	5.8 (±3.2)

Pcl: pulmonary clearance; PCD: primary ciliary dyskinesia, mean ±(SD).

Table 3. – Anthropometric data; results of the determination of Pcl by the plasma sample method

Normal individuals	Sex	Age yrs	Height cm	Weight kg	^{51}Cr - EDTA ml·min^{-1} clearance	ECV ml	$\bar{t}$(ECV+L) min	$\bar{t}$(ECV) min	$\bar{t}$(L) min
1	M	22	171	70	96	14208	477	148	329
2	M	18	183	77	89	15219	623	171	452
3	M	20	180	68	84	17976	632	214	418
4	F	27	166	50	79	12640	463	160	303
5	F	27	170	65	70	10570	492	151	341
6	M	25	176	66	101	14847	621	147	474
7	M	24	183	68	119	16184	389	136	253
8	M	23	171	60	103	15141	776	147	629
9	M	19	188	74	83	21165	386	255	131
$\bar{x}$		23	176	66	92	15328	540	170	370
SD		3.3	7.4	7.9	14.8	3025	130.5	39.2	143.5
PCD patients									
1	F	24	160	50	91	8463	619	93	526
2	M	44	167	69	45	14040	966	312	654
3	F	23	161	83	78	15990	1318	205	1113
4	M	17	173	63	104	11336	1151	109	1042
5	F	36	173	55	85	11475	941	135	806
6	M	14	165	52	117	14742	844	126	718
7	M	20	185	82	150	15150	370	101	269
8	F	12	148	42	79	9717	628	123	405
9	F	30	176	60	110	16060	600	146	454
10	F	15	165	53	101	12524	530	124	406
11	F	30	163	53	90	14580	567	162	405
12	F	17	165	54	91	12467	551	137	414
13	F	31	167	63	130	14300	622	110	512
14	F	34	162	56	78	8970	689	115	574
$\bar{x}$		25	166	60	96	12844	743	143	593
SD		9.6	8.6	11.7	25.6	2543	265.3	56.3	249.6

ECV: extracellular volume; $\bar{t}$(ECV+L): mean transit time (t) for the transport of ^{99m}Tc-DTPA from the lungs to the kidneys; $\bar{t}$(ECV): $\bar{t}$ for the transport of ^{99m}Tc-DTPA through the ECV; $\bar{t}$(L): $\bar{t}$ for the transport of ^{99m}Tc-DTPA across the alveolar capillary membrane.

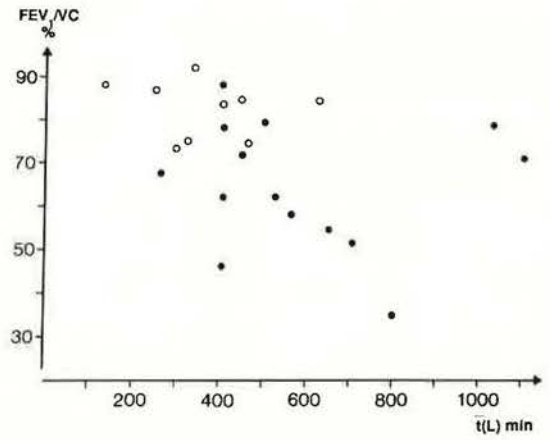

Fig. 3. – A comparison between the individual FEV_1/VC and transit time, $\bar{t}$(L), values of the normal individuals (●) and the patients PCD (○).

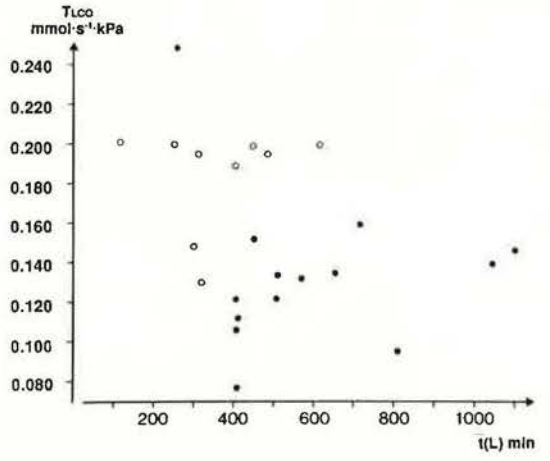

Fig. 4. – A comparison between individuals TLCO and transit time, $\bar{t}$(L), values of the normal individuals (●), and the patients with PCD (○).

Discussion

The results of this study show that patients with primary ciliary dyskinesia (PCD) have a decreased overall pulmonary clearance (Pcl) of aerosolized ^{99m}Tc-DTPA.

It has recently been shown that DTPA is firmly bound to mucus [13]. This is consistent with the results of this study of regional Pcl, where we found a slower clearance rate in the central parts of the lungs than in the periphery of the control individuals and a similar trend in the patients with PCD. But does the pattern of aerosol deposition also explain the results of the difference in overall Pcl between the two groups? We did find an increased central deposition of the aerosol in the patients with PCD as is usually the case when patients with obstructive lung disease are studied [14]. The increased aerosol deposition in the airways probably also includes the small airways. If, in the transition between the mucus and the non-mucus lined airways, the mucous layer is so thin that DTPA may after all diffuse through it during the examination period, this may affect both the overall Pcl as measured by the plasma sample method and the initial Pcl of the lung periphery as measured by the gamma camera method. The same might be the case if in patients with PCD there should be an isolated defect of the airway epithelium permeability. There was, however, no correlation between the mean transit time (t(L)) for the transport of ^{99m}Tc-DTPA across the alveolar capillary membrane as measured by plasma samples and the degree of air-flow limitation. In an earlier study of patients with obstructive lung disease, HUCHON *et al.* [15] were not able to demonstrate any change in Pcl either. The pattern of deposition is, therefore, not likely to be the only explanation of our results.

The main pathway of DTPA from the lungs to the blood is generally thought to be *via* the tight junctions between alveolar cells. DTPA is a hydrophilic molecule with a diameter of about 0.5 nm [16]. The equivalent pore radius of the tight junctions between alveolar cells has been estimated to be 0.8–1.0 nm [17]. It has been suggested that the diameter of the tight junction should yield passively to stretch [18]. Animal studies have shown that *i.v.* injection of olein induces an immediate increase in Pcl as measured by the external detection method [19]. This observation is difficult to explain by a concept of a single, passively regulated pore size between alveolar cells as the only limiting factor in the transport of ^{99m}Tc-DTPA from the lungs to the blood.

In most conditions the first part of the externally derived time activity curve seems to be well defined by a monoexponential fit. But in adult respiratory distress syndrome (ARDS) [20], where the clearance rate is very fast, the time activity curve is better defined by a biexponential fit. The physiological significance of two curve components is unclear, but does indicate that it is probably too simplified to consider a single size of the lumen of the tight junctions as the only limiting factor in the transport of ^{99m}Tc-DTPA from the lungs to the blood.

Individuals with respiratory distress syndromes are severely deficient of alveolar surfactant. Smokers also have reduced production of surfactant [21] and a fast ^{99m}Tc-DTPA clearance rate [22]. Surfactant lining may, therefore, be associated with alveolar epithelial permeability. In fact WOLLMER *et al.* [2] found an increased pulmonary permeability of surfactant depleted rat lungs and suggested that surfactant may constitute a limiting factor in pulmonary clearance of ^{99m}Tc-DTPA. The externally detected Pcl values of this study, being less than $15x10^{-3}$·min^{-1} agree with previous observations in non-smokers. They are also in line with a possible association between surfactant and pulmonary permeability, since the patients with PCD could be expected to have decreased alveolar clearance of surfactant.

However, it is not obvious why surfactant should constitute a limiting factor. GUYTON *et al.* [23] have suggested the existence of a mechanism in which fluid filters out of the alveolar septum and then moves along the septal surface to the alveolar corners and apices where it is absorbed back into the interstitium through an epithelium that may be specialized for absorption. The experimental observation that fits with the existence of such a mechanism is the observation that when fluid containing dyes is instilled into the alveoli it moves almost instantly to the corners and there disappears into the junctional interstitium. If the reduced bronchial clearance of surfactant in Pcl is associated with an impaired alveolar wash mechanism, this may explain the decreased Pcl in patients with PCD.

Moreover, according to Fick's first law of diffusion, pulmonary clearance of ^{99m}Tc-DTPA would be expected to be proportional to PS/V [24], where P is the permeability, S is the surface area of the lung membrane, andV is the volume of fluid lining the lungs. If a consequence of a reduced alveolar clearance of surfactant is an overall increase in alveolar lining fluid, this would be consistent with a decreased Pcl.

On the other hand, in adult respiratory distress syndrome (ARDS) there is a pulmonary oedema and a severe increase in V, but also an increased Pcl. This, however, does not necessarily invalidate the possibility of a high V and a low Pcl since, as suggested by MASON *et al.* [25], in ARDS the alveolar flooding is so severe that the ^{99m}Tc-DTPA aerosol may not penetrate to the alveoli. It is probably deposited on extremely leaky terminal airways.

Pcl is increased during positive end expiratory pressure (PEEP) [26] and at high lung volumes *i.e.* when S is large [17, 27]. The TLC and VC of the PCD patients were quite low and despite the fact that eight of the patients had an obstructive lung disease the average RV/TLC was not increased (table 1). A decreased S of the PCD patients may therefore also explain the difference in Pcl between the groups.

In conclusion, patients with PCD may have reduced Pcl in comparison with normal individuals. The reason for this is unclear and several mechanisms may be involved. Reduced bronchial clearance of surfactant in PCD may be associated with an increased alveolar lining fluid volume and/or an impaired movement of

^{99m}Tc-DTPA along the alveolar septa to the bronchoalveolar junction, where the epithelium may be more specialized for absorption. In addition, the patients with PCD had small lung volumes, which in itself may theoretically be associated with reduced Pcl values.

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Perméabilité pulmonaire dans la dyskinésie ciliaire primitive. S. Groth, M. Pedersen.

RÉSUMÉ: La clearance pulmonaire du ^{99m}TcDTPA administré en aérosol, a été étudiée chez 14 patients atteints de dyskinésie ciliaire primitive (PCD) (âge moyen 23.5 ans, extrêmes 12–44 ans) et chez 9 individus normaux (âge moyen 23 ans, extrêmes 18–27 ans). Aucun n'avait jamais fumé. La clearance pulmonaire régionale a été étudiée pour des régions centrales et périphériques du poumon arbitrairement définies grâce à une méthode à la gamma caméra, tandis que la clearance pulmonaire totale a été étudiée par échantillonnage du plasma. Les patients atteints de dyskinésie ciliaire primitive avaient une clearance pulmonaire totale réduite par comparaison avec les individus normaux ($p<0.05$), ainsi que des valeurs significativement plus basses de la CPT, de la CV, du VEMS et du rapport VEMS/CV ($p<0.05$). Il n'y avait pas de corrélation entre la clearance pulmonaire et le rapport VEMS/CV. On conclut que la diminution de la clearance pulmonaire chez les patients atteints de dyskinésie ciliaire primitive, pourrait être en rapport avec leurs petits volumes pulmonaires. En outre, la diminution de la clearance bronchique du surfactant dans les dyskinésies pulmonaires primitives, pourrait être associée à une augmentation du volume de liquide de recouvrement alvéolaire et/ou avec un déplacement diminué du ^{99m}Tc-DTPA le long des septa alvéolaires vers la jonction broncho-alvéolaire où l'épithélium pourrait être plus spécialisé dans l'absorption.

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