Electromanometric function test of the nasofrontal duct

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SUMMARY

An electromanometric method for the quantitative measurement of the ventilation of the frontal sinus is described which also measures the resistance of the nasofrontal duct to an experimentally produced hydrodynamic current. The biophysical basis as well as typical results of the examination are demonstrated and the field of clinical application in the differential diagnosis of frontal sinus affections is outlined.

The literature can be found in the study by R. Zippel, K. Vogt and W. Grützmacher, „Eine elektromanometrische Methode zur Funktionsprüfung des Ductus nasofrontalis", Arch. Oto-Rhino-Laryng., 208, 1-14 (1974).

A function test of the nasofrontal duct must answer two questions whose central importance in the pathophysiology of the nasal sinus system should be undisputed:

1. Are the physiological pressure variations in the nose and nasopharynx effective in the frontal sinus?
2. In ventilation disorders, how great is the resistance of the nasofrontal duct to such pressure variations and to the outflow of secretions from the frontal sinus?

For the quantitative assessment of the pressure balance between nose and frontal sinus an apparatus was developed and tested in the last 2 years in collaboration with the VEB Kombinat Messgerätewerk Zwönitz. Also the biophysical basis was worked out for a diagnostic procedure which allows important conclusions on the pathophysiology and systematics of frontal sinus affections.

The apparatus consists of an electromanometer, type Biomonitor 301 or 401, with a measuring range increased to 800 Torr, and an accompanying pressure converter acting on the principle of a semiconductor expansion measuring strip. The initial signal from the Biomonitor is conducted to the wide-graph channel of a 3-channel electrocardiograph (3-NEK 116) for recording. In the shunt of the tap system of the pressure converter there is an injector developed by us whose possible injection rates lie above those of the usual perfusion instruments and below those of high-pressure injectors used in cardiovascular X-ray diagnosis. The electronic regulation of the injector permits constant injection rates even

Figure 1 - 4. Pressure changes in the frontal sinus with pressure variations in the nose.

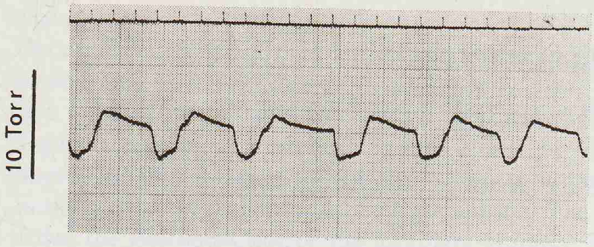


Figure 1. Normal nose breathing.

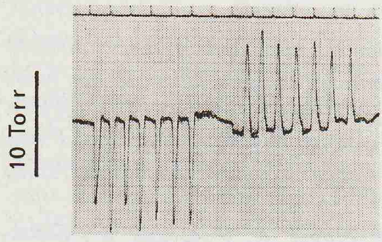


Figure 2. Forced inspiration and expiration (sniffing and blowing the nose).

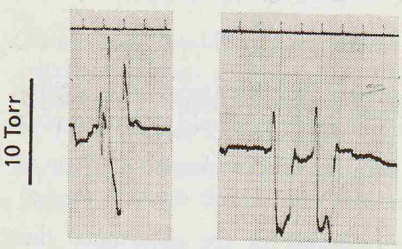


Figure 3. Toynbee's test.

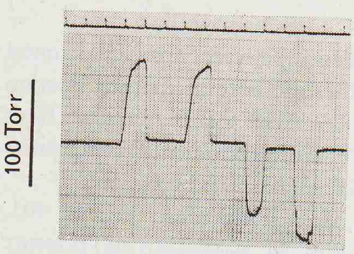


Figure 4. Valsalva and inverted Valsalva test.

against considerable counterpressure. The injection rate (revolution rate) of the apparatus can be recorded on another ECG channel.
The examination begins with Kümmel-Beck drilling followed immediately by the ventilation test of the frontal sinus. The waterfilled tube system is connected with the lumen of the in-dwelling cannula via a polyethylene capillary, then the pressure variations on breathing, blowing the nose and sniffing are examined,

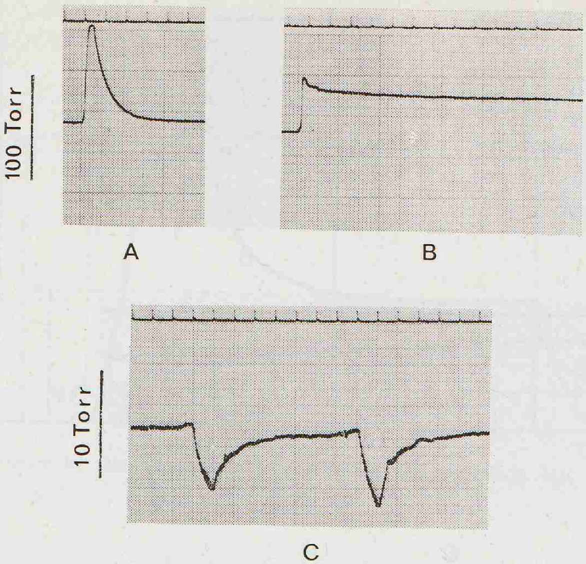


Figure 5. Ventilation disturbances in the frontal sinus.
A - slightly, B - greatly prolonged balancing time after Valsalva test, C - much reduced pressure difference with inverted Valsalva test with delayed pressure balance.

followed by Toynbee's, Valsalva's and the inverted Valsalva test. Normal curves of these tests are shown in Figures 1 to 4.

In contrast to our first publication we have now come to the opinion, on the basis of observations with the much improved measuring system, that the normal respiratory pressure variations in nose and nasopharynx can be recorded under physiological conditions of the frontal sinus and that occlusion of the nasofrontal duct represents a pathological condition.

Even with slight function disturbances of the nasofrontal duct the pressure changes during quiet nose breathing are no longer recordable, later those during forced respiratory movements disappear and finally even the Valsalva and the inverted Valsalva test no longer produce any pressure changes in the frontal sinus. Ventilation disturbances can manifest themselves either in an absence of pressure rises or falls during the appropriate ventilation test or in a delayed balancing time of the pressure differences produced in the frontal sinus (Figure

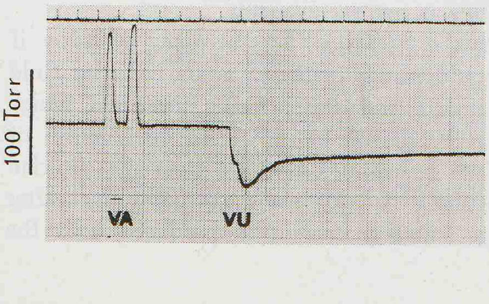


Figure 6. Valve effect. Normal pressure balance with Valsalva test (VA) and delayed pressure balance after inverted Valsalva test (VU).

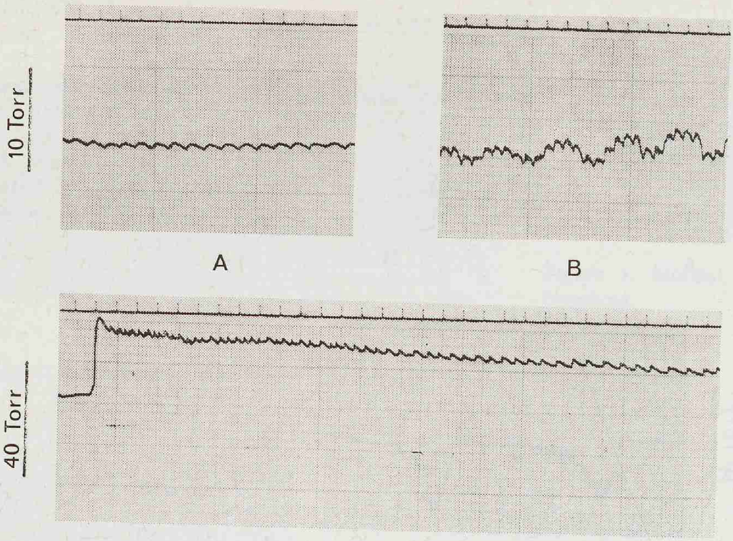


Figure 7. Superimposition of bloodpulsations. A. in obstruction of the nasofrontal duct. B. in nasal breathing. C. in delayed pressure aequalization after Valsalva's manoeuvre.

5). In individual cases a ventilation disturbance in the nasofrontal duct can be assumed also from the way the pressure behaves after the creation of positive and negative pressure. According to the passage direction, there may be either a "positive pressure valve" or a "negative pressure valve" (Figure 6).
In inflammatory processes the pressure change curves are occasionally superimposed by pulse waves which can be objectively demonstrated by simultaneous recording of the finger pulse. Pulse waves can also be demonstrated in occlusion of the nasofrontal duct directly after introduction of the measuring capillary into the frontal sinus (Figure 7).
The normal values measured by us in the frontal sinus correspond to those last measured by Pfretzschner and Loibl in the maxillary sinus. We now consider it possible that, through the jet action in the middle nasal duct pressure, differences in the frontal sinus are created which are greater than those in the middle nasal duct itself. Objective proof of this is not yet available.
The second part of the function test, the perfusion test, becomes necessary if the ventilation test has shown pathological resuls. In these cases a laminary fluid current is created in the nasofrontal duct and the pressure measured which is required to maintain this current at a constant velocity, i.e. the criterion of "good, impeded or abolished lavability" is quantified which gives the clinician some rough information on the functional state of the nasofrontal duct after Kümmel-Beck drilling. The necessary laminary current is produced with the

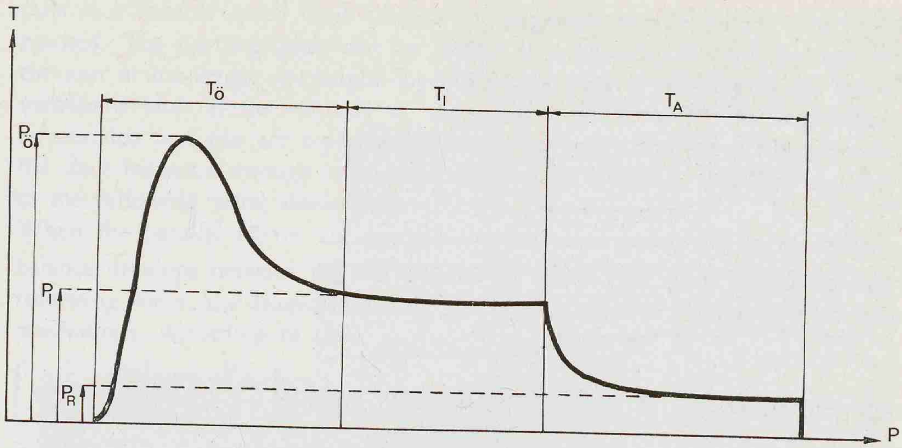
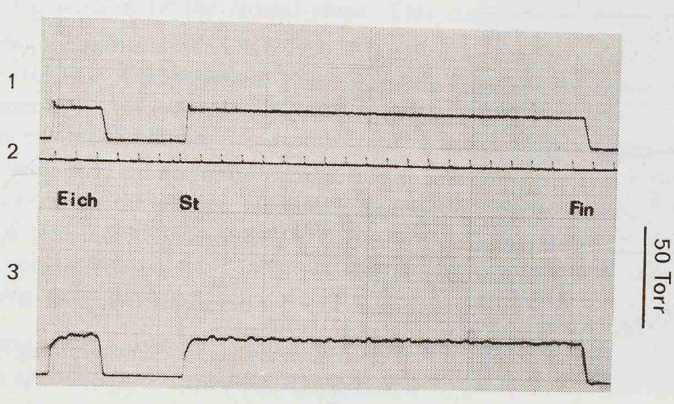


Figure 8. Decrease of pressure during the perfusion test (schematic).

above-mentioned injector which is connected with the two-way system of the pressure converter. The pressures occurring during the perfusion test may be divided into 3 phases during which different biophysical regularities are effective (Figure 8).

During the opening phase Tö, the pressure in the frontal sinus rises to a critical opening pressure Pö. The steepness of the rise depends on the instillation velocity I, the size of the frontal sinus and the proportion of compressible gas in the total volume of the frontal sinus. Since in the sitting patient the instilled water

Figure 9. Perfusioncurve in open nasofrontal duct.
1. Velocity (rotation number)
2. Time
3. Pressure decrease. Eick-Calibration curve of the polyaethylene tube; St., Fin - Start resp. termination of the perfusion.



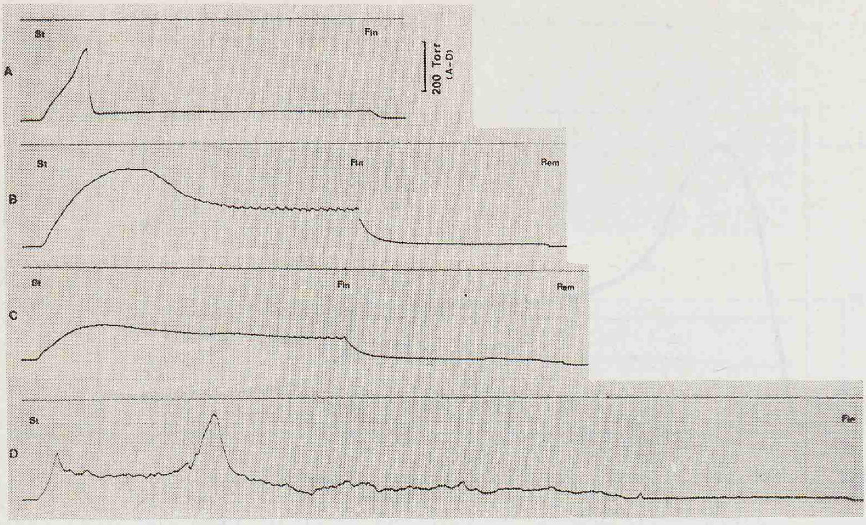


Figure 10. Hydrodynamic function test. Pathological curves. St. - Start; Fin - termination; Rem - removal of perfusion tube. A. considerably increased opening pressure, increased residual pressure. B., C. Opening pressure, perfusion pressure and residual pressure increased, prolonged opening and aequalization period. D. Irregular curve form during washing out of mucopus, after which perfusion pressure becomes normal.

runs to the fundus of the frontal sinus and therefore the gas present in the frontal sinus cannot escape, an air chamber is formed which later may affect the balancing phase. After exceeding the critical opening pressure the pressure in the system

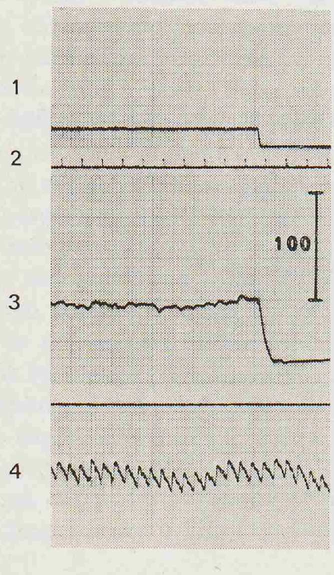


Figure 11. Superimposition of pulse at the end of the perfusion phase.
1. Rotation recording, 2. Time recording, 3. Pressure decrease, 4. Finger pulse.

falls at a variable speed until a curve approximately parallel to the zero line is reached. The opening peak may be absent if a laminary current sets in from the start of the lavage. Its height depends on the state of swelling of the mucous membrane and on the viscosity of the secretion present. To the same degree as secretion and pus are replaced by the lavage water and the actual radius of the duct increases through subsidence of mucosal swelling, the flow resistance to the fellowing water diminishes.

When the parallel curves are reached the perfusion phase T_I begins. Since a balance develops between the air chamber in the frontal sinus and the steadily following water, the Hagen-Poiseuille flow law applies to this phase with some reservations. According to this,

$\left[W = \frac{8\eta l}{\pi R^4} = \frac{P_I}{I}\right]$, where W is flow resistance of the nasofrontal duct in PRU, I is hydrodynamic flow intensity in ml/min, P is lavage pressure in Torr, l is length of the nasofrontal duct and R is radius of the nasofrontal duct. The equation shows that the hydrodynamic resistance is directly proportional to the length of the tube but changes of the radius enter the equation to the power of 4. Since changes in length of the duct as an intraindividual process hardly play a part, differences between flow resistances in the same patient are a very sensitive indicator of changes in the functional state of the nasofrontal duct.

The measuring unit for the resistance is the peripheral resistance unit (PRU). 1 PRU is the resistance at which a pressure difference of 1 Torr produces an installation velocity of 1 ml per minute.

Calculation of the radius is possible with some reservations but is not necessary because, as a function-diagnostic quantity, only the resistance of the nasofrontal duct is of interest. After the end of the perfusion phase the pressure gradient in the measuring system collapses rapidly. Now follows the compensation phase T_A. Analogous to the results of the ventilation test the pressure balance may be considerably impeded. The compensation time is then prolonged. If the pressure curve does not reach the zero line even after a prolonged period, a residual pressure P_R remains in the frontal sinus. This corresponds to the critical occlusion pressure of the nasofrontal duct. According to our experience this must be less than 10 Torr. Compensation time and critical occlusion pressure are objective measurements of the adaptability of the frontal sinus to pressure variations in the nasal cavity. While in the normal case, using a flow velocity of up to 30 ml/min, only that pressure during the lavage is measured which corresponds to the resistance of the lavage capillary (Figure 9), with nasofrontal duct radii below 0.4 mm pathological pressure curves are recorded whose evaluation allows accurate conclusions on the content of the frontal sinus and its outflow path to the middle nasal duct.

Thus during the lavage of inflamed frontal sinuses there occurs nearly always a typical opening peak, followed by a curve section at a raised level during the

	Durchströmungsprüfung						Ventilationsprüfung							
	$T_ö$	$P_ö$	R	T_A	P_{Re}		Resp.	Info	Exfo	Toy	Va	T_{AVa}	Vu	T_{AVu}
1. Tag	10	320	8.6	2.0	30	Eiter	∅	∅	∅	∅	4	>45	-5	>70
4. Tag	20	230	5.5	2.4	8	klar	+1, -1	-3	1.2	+1, -2	40	1.4	-16	1
7. Tag	1	=P_1	0.7	2.0	0	klar	+2.5, -6	-10	2.5	+3, -4	70	0.6	-64	1

Table 1. Follow up during the healing process of an acute frontal sinusitis.
$T_ö$, $P_ö$ — Openingtime, pressure
R — Resistance
T_A — Aequalization time
P_{RE} — Residual pressure (or pressure change in nasal breathing)
Info, Exfo — forced inspiration or expiration
Toy — Toynbee's manoeuvre
T_{AVa}, T_{AVu} — Aequalization time Valsalva's manoeuvre
Time in sec. Pressure in Torr.

perfusion phase too. Subsequently in the compensation phase the pressure created often falls only slowly or there remains a residual pressure in the frontal sinus until the lavage capillary is removed (Figure 10 A-C). If there is mucopus of considerably increased viscosity in the frontal sinus, the lavage curve remains irregular until the lavage fluid is clear (Figure 10 D). During the perfusion phase as well as during the compensation phase the pressure curve may be superimposed by pulse waves (Figure 10 B, 11).

The considerable clinical importance we attribute to the described method of examination is demonstrated by an example of the numerical evaluation of a case (table 1).

In a patient aged 38 there were increasing left-sided frontal headaches and increasing tenderness on pressure on the base of the frontal sinus for 4 days after an infection of the upper airways. Standard radiography of the nasal sinuses showed diffuse opacity of the large left frontal sinus. Kümmel-Beck drilling was decided upon with the diagnosis of acute frontal sinusitis and suspected early orbital complication. The 1st function test was performed immediately following the drilling, showing that ventilation was almost abolished, opening pressure and lavage resistance greatly increased, with a residual pressure of 30 Torr at the end of the balancing phase. 3 days later the ventilation was reestablished, the perfusion test values were still pathological but clearly improved. On the 7th day the frontal sinus was properly ventilated and the perfusion test showed normal values.

The selectivity of the described procedure induces us to employ it in clinical practice for the diagnosis of rhinological conditions as follows:

1. For the differential diagnosis of frontal headache and definite exclusion of ventilation disturbances of the frontal sinus.

2. For observation of the course of inflammatory conditions of the frontal sinus and for the assessment of the result of conservative treatment.

The accurate quantitative asessment of the function of the nasofrontal duct made possible by the method here presented should make the beginning of a differentiated consideration of the actiology, the differential diagnosis and finally of the systematics of frontal sinus affections. The present study is to form the technical and biophysical basis for this.

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