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The effect of physical work on the mucosal blood flow and gas exchange in the human maxillary sinus

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SUMMARY

The paranasal sinuses are lined with respiratory mucosa of principally the same structure as in the nasal mucosa but somewhat thinner. This mucosa has a rich blood flow and advanced system of blood vessels regulated mostly by the autonomous nervous system but also by other factors as acid/base balance and endocrine activity. The thickness of the nasal mucosa regulates the nasal breathing resistance and varies with among other factors, body activity.

In this investigation we have studied the effect of physical work on the human maxillary sinus mucosa.

The investigation shows that, as in the nose, the blood flow and the pulse amplitude are considerably reduced during physical work, in situations of heavy work falling to about half of the normal level, and probably result in the redistribution of blood from the respiratory mucosa. The gas exchange in the paranasal sinus is reduced only to a small extent, the reduction being too small to change the antral gas composition towards pathological conditions.

According to Rahn and Van Liew (1955), the maxillary sinus is a non-collapsable gas pocket connected to the nasal cavity through, generally one narrow canal. The sinus is lined with respiratory mucosa slightly thinner than that in the nose but with the same components and the same architecture. The maxillary sinus, with its bony walls and narrow ostium, makes it an ideal "model" for experiments on mucosal gas physiology and blood flow. Its volume is constant and can be calculated, the mucosal surface area and volume estimated and its entrance, the ostium, experimentally easily occluded and reopened without harming the investigated person.

Richerson ad Seebohm (1969) reported that the thickness of the nasal mucosa is reduced during physical exercise, partly due to hormonal and partly to nervous reasons. Melen (1986) showed that the ostial resistance decreased after physical work. This reduction in mucosal thickness, giving reduced nasal breathing resistance, is a result of a lower blood flow and a reduced blood content in the mucosa. During physical exercise the blood is redistributed from the nasal, tracheobroncheal mucosa and the intestines to the muscles, heart and skin.
The aim of this investigation is to study the effect of physical exercise on normal physiology regarding gas exchange and blood flow and content in the mucosa of the human maxillary sinus.
The following phenomena in the mucosa were therefore studied during rest and during physical work since we believe these to be the major mucosal factors for keeping the sinus healthy:

1. the mucosal pulse amplitude and frequency;
2. the mucosal blood flow;
3. the mucosal gas exchange.

MATERIAL AND METHODS

In this series of investigations five healthy persons aged 21 to 42 years participated. None of them had had any history of nasal or antral infection for the last two months before the investigation. All five had normal anatomy in the nose and the maxillary sinus.
The investigation was performed in healthy, human maxillary sinuses with experimentally occluded ostia.
The variations in pulse amplitude, pulse frequency and blood flow were recorded as intra-antral pressure variations. The measurements of the blood flow were pletysmographic. The pressure rise in the investigated sinus caused by bilateral compression of the interal jugular veins was recorded for 10 seconds. From the increase in antral pressure during the 10 seconds, the mucosal blood flow could be calculated (Drettner and Aust, 1974).
The pressure variations were measured with a manometer EMT 33 (Elema Schönander) connected via a plastic tubing, 800 mm long and with an inner diameter 0.8 mm, to a cannula with an inner diameter of 1.2 mm introduced into the investigated antrum through the medial sinus wall in the lower nasal meatus. The signals from the manometer were amplified in an EMT 31 (Elema Schönander) amplifier and recorded with a Mingograph 32 (Elema Schönander).
The gas exchange was studied by aspiration of gas samples of 5 mm^3 from the investigated sinus through the cannula with an air-tight syringe. The samples were analysed in a Varian gas chromatograph.
Variations in gas volume during the experiments were measured with a simple volumeter consisting of a horizontal glass tube with an inner diameter of 2 mm

and with a length 400 mm, containing a drop of water as an indicator. A ruler marked in mm was mounted behind the glass tube. During the volumetric recordings the glass tube was connected via a plastic tube and a cannula to the investigated sinus. The volume variations were illustrated by the movement of the water drop.

The physical exercise in the study was performed on an bicycle ergometer. In experiments concerning pulse amplitude and blood flow, the investigated persons were riding the bicycle with an increasing load beginning at 50 W and via 100 W and ending at a load of 150 W, three minutes at each load. In the experiments concerning gas exchange the investigated persons were pedaling the bicycle for ten minutes with a load of 100 W. During the bicycle ride the cardiac activity was controlled with ECG and no pathology was found within the group of investigated cases before, during or after the experiment.

The volume of the sinus was calculated according to Boyle's law. 50 μl of air was introduced into the experimentally occluded sinus (Figure 1). The volume and the pressure rise in the antrum cased by the insufflated air together with the inital antral gas pressure gave the volume of the sinus (Ingelstedt et al., 1967; Aust and Helmius, 1974).

$$P \times V = P^1 \times V^1$$

P = the initial pressure in the maxillary sinus.
V = the antral volume + manometrical system volume.
P^1 = the antral pressure after insufflation of 50 microliters of air.
V^1 = sinus volume + manometrical system volume minus 50 microliters of air.

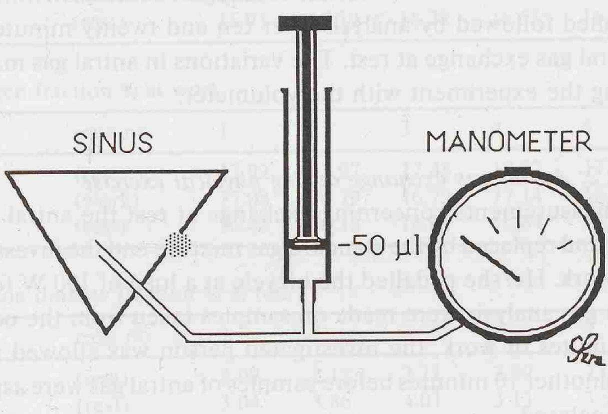

Figure 1. Equipment for measuring the volume of the maxillary sinus.

PROCEDURE OF THE EXPERIMENTS

The persons participating in the study were thoroughly examined and if healthy they were allowed into the experiments.

The middle and the lower nasal meatus in the widest of the nasal cavities were anaesthetised with Xylocain® dental spray 10% and the cannula connected to the manometer was introduced into the investigated maxillary sinus.

First, the patency of the ostium was estimated. If there were pressure variations generated by and synchronous with nasal breathing registered in the sinus the ostium was regarded as normal and patent. The next step in the experiment was to occlude the ostial canal with Spongostan® moistened in Xylocain® gel.

When the pressure variations in the sinus were replaced by pulse waves the ostium was regarded as closed and the investigation could begin. The experiments started with the insufflation of 50 microliters of air into the investigated antrum, causing a pressure rise which made it possible to calculate the sinus volume according to Boyle's law, as mentioned above.

In order to standardize the antral conditions in the study before each series of experiments, the air in the investigated sinus was washed out for three minutes with, and replaced by a gas mixture pre-heated to 37° and humidified to 100%. The gas mixture contained 18.4% O_2, 2.09% CO_2, 1.04% Ar, and 78.47% N_2. This gas mixture is a standard gas, composed from the means of the partial pressures of oxygen, carbon dioxide, argon and nitrogen in gas samples taken from 10 normal maxillary antra with patent ostia.

Experiment 1: Antral gas exchange at rest

After replacing the antral gas, the experiments started by the investigated subject being placed on a bicycle ergometer with ECG electrodes attached to her/his chest and a cannula introduced into the investigated sinus. An initial gas analysis was performed followed by analysis after ten and twenty minutes to illustrate normal antral gas exchange at rest. The variations in antral gas mass were registered during the experiment with the volumeter.

Experiment 2: Antral gas exchange during physical exercise

After the measurements concerning exchange at rest the antral gas was again washed out and replaced by the standard gas mixture and the investigated subject was set to work. He/she pedalled the bicycle at a load of 100 W for 10 minutes, after which gas analysis were made on samples taken from the occluded sinus. After 10 minutes of work, the investigated person was allowed to rest on the bicycle for another 10 minutes before samples of antral gas were aspired from the sinus and analysed.

During the experiment, the gas mass was registered with the volumeter.

Experiment 3: Antral pulse and blood flow at rest and during physical exercise
In this experiment, antral blood flow was measured plethysmographically and the pulse amplitude manometrically. Pulse frequency was measured both manometrically and with an electrocardiogram. The registrations were made both at rest and during physical exercise performed on a bicycle ergometer in 3-minute periods with loads of 50 W, 100 W and 150 W. Registrations of pulse amplitude and frequency were made before the physical exercise started and then every minute during the experiment. The blood flow was measured after each 3-minute period of physical exercise. After the series of experiments, the investigated person rested for nine minutes before a final registration of the three parameters was made.

RESULTS
In the experimentally occluded sinuses, the oxygen fraction at rest after ten minutes was reduced by 0.85% and during the following 10 minutes by another 0.58% (Table 1 and Figure 2).
After physical exercise for 10 minutes with a load of 100 W the oxygen fraction was reduced by 0.94% and after another 10 minutes the oxygen fraction was further reduced by 0.61% (Table 2 and Figure 2).
In the investigated, occluded sinus, the carbon dioxide fraction at rest during the first 10 minutes increased by 1.37% and after another 10 minutes increased by an additional 0.87% (Table 3 and Figure 3).

Table 1. Oxygen fraction % at rest

time min.	case no.	1	2	3	4	5	mean
0	(rest)	17.92	18.16	17.72	17.69	17.79	17.86
10	(rest)	17.25	17.02	16.87	17.19	16.70	17.01
20	(rest)	16.91	16.39	16.28	16.55	16.02	16.43

Table 2. Oxygen fraction % at work

time min.	case no.	1	2	3	4	5	mean
0	(rest)	17.92	17.97	17.48	17.92	17.72	17.80
10	(work)	17.08	16.79	16.72	17.14	16.57	16.86
20	(rest)	16.43	16.18	16.05	16.84	15.76	16.25

Table 3. Carbon dioxide fraction % at rest

time min.	case no.	1	2	3	4	5	mean
0	(rest)	2.09	2.12	2.31	2.09	2.09	2.14
10	(rest)	3.04	3.86	4.01	3.13	3.55	3.51
20	(rest)	3.74	4.76	5.05	3.84	4.50	4.38

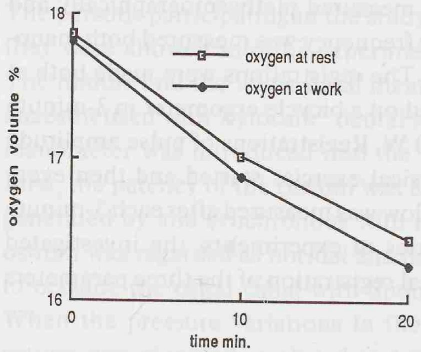

Figure 2.
Oxygen change during rest and work.

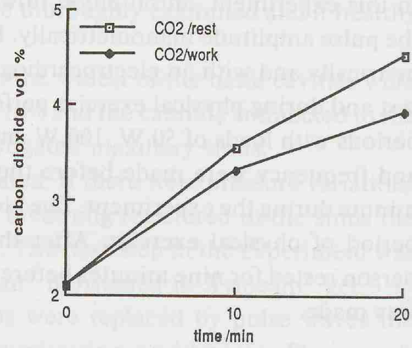

Figure 3.
CO_2 change during rest and work.

Table 4. Carbon dioxide fraction % at work

time min.	case no.	1	2	3	4	5	mean
0	(rest)	2.09	2.22	2.35	2.15	2.09	2.18
10	(work)	2.85	3.36	3.74	3.32	3.32	3.32
20	(rest)	3.51	4.18	4.70	4.12	3.93	4.09

After physical exercise during 10 minutes with a load of 100 W the carbon dioxide fraction increased by 1.14% and after another 10 minutes the carbon dioxide fraction increased by additional 0.77% (Table 4 and Figure 3).

The variation gas mass in the investigated sinus was followed with our volumeter which is accurate and has no compliance or technical complications. The measurements illustrate that the total gas mass increases in the occluded sinus at rest. Falck (1989) has shown that the gas mass increases during the first 25 minutes. Thereafter, the gas mass decreases and after about 120 minutes the gas volume is approaching steady state.

At work, the initial increase of gas mass is much less than at rest and the decrease starts already after 10 minutes. The initial value of gas mass in this situation is reached after 20 minutes whereafter the gas mass is further decreased (Figure 4). The studies of frequency and amplitude of the antral pulse wave at rest and during physical exercise showed that during work the frequency increased and the amplitude decreased proportionally to the load on the bicycle ergometer (Figure 5).

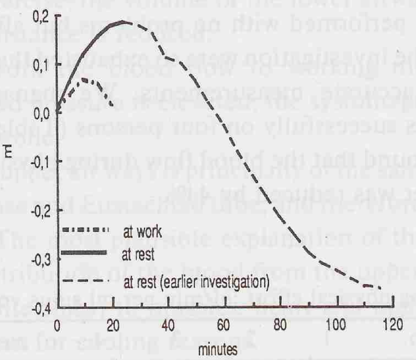

Figure 4. Variation in antral gas mass in occluded sinus during rest and physical work. The first 20 minutes in the figure are based on experiments in this study. The recordings from 20 to 120 minutes are based on a parallel study concerning gas exchange in the occluded maxillary sinus (Falck et al., 1989).

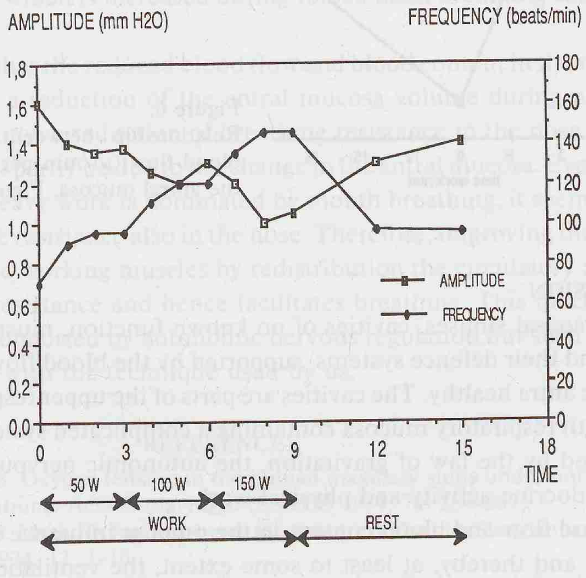

Figure 5. Pulse amplitude and frequency in the maxillary mucosa during and after physical work.

The blood flow in the antral mucosa was measured plethysmographically. At rest, the measurements were performed with no problems but after heavy physical exercise the persons in the investigation were so exhausted that there were some difficulties in making accurate measurements. We managed, however, to perform the experiments successfully on four persons (Table 5 and Figure 6). In our experiments we found that the blood flow during physical work of 150 W on the bicycle ergometer was reduced by 44%.

Table 5. Blood flow during physical effort, μl/min per ml sinus volume.

time min.	case no.	1	2	3	4	mean	%	Δ%
0	(rest)	13.2	22.8	9.7	13.7	14.9	100	0
3	(50 W)	14.3	16.8	7.2	9.4	11.9	80	−20
6	(100 W)	10.4	18.3	8.6	9.8	11.8	79	−21
9	(150 W)	8.4	12.1	6.4	6.4	8.3	56	−44
18	(rest)	9.2	18.3	8.5	14.5	12.6	85	−15

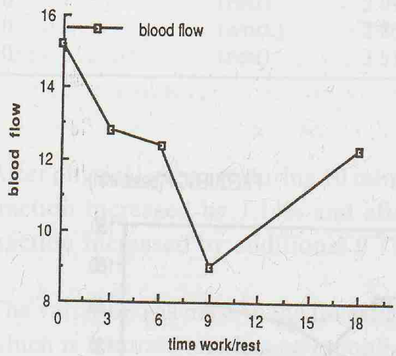

Figure 6.
Relationship between physical work and blood flow (μl/min per ml sinus volume) in the antral mucosa. Figure based on Table 5.

DISCUSSION

The paranasal sinuses, cavities of no known function, must be properly ventilated, and their defence systems, supported by the blood flow, must be intact to keep the antra healthy. The cavities are parts of the upper respiratory system and lined with respiratory mucosa containing a complicated system of blood vessels controlled by the law of gravitation, the autonomic nervous system, heat and cold, endocrine activity and physical work.

The blood flow and blood content in the mucosa influence the nasal breathing capacity and thereby, at least to some extent, the ventilation of the paranasal sinuses by regulation of the thickness of the mucosa of the upper airways.

During physical exercise, the volume of the lower airways is increased and the nasal breathing resistance is reduced.

During physical work the blood flow to working muscles, heart and skin increases. The blood pressure is elevated, the systolic pressure being increased more than the diastolic.

The mucosa in the upper air ways is principally of the same structure in paranasal sinuses as in the nose and Eustachian tube, and therefore reacts in the same way to physical work. The most plausible explanation of the reduction in mucosal thickness is a redistribution of the blood from the upper respiratory airways (as well as from the intestines) to muscles, heart and brain. The blood flow also increased in the skin for cooling reasons.

The reduction of blood flow in the airways results in a decreased respiratory resistance and improves the breathing capacity during physical work.

The distribution of blood in the capillary beds in the body is mostly a result of the tone in the autonomous nervous system but also hypoxaemia has an influence on blood distribution. The latter factor may be of special importance in the antra.

The ventilation of the paranasal sinuses, both perostial and mucosal, has been regarded by many authors (Drettner, 1965; Aust and Drettner, 1974) as the most important factor for the sinus to remain healthy.

In this investigation we can see that during physical effort the blood flow and blood content in the antral mucosa is considerably reduced, resulting in a thinner respiratory mucosa. The reduction in mucosal gas exchange is marginal to the perostial ventilation which is increased during forced nasal breathing caused by heavy work.

Further, we can see that the reduced blood flow and blood content in the respiratory mucosa causes a reduction of the antral mucosa volume during physical exercise. The well-known reduction of breathing resistance in the nose during exercise must at least partly be due to the change in the antral mucosa. Even if the ventilation during heavy work is dominated by mouth breathing, it seems to be convenient to reduce resistance also in the nose. Therefore, improving the blood flow available for the working muscles by redistribution the circulatory adaptation reduces nasal resistance and hence facilitates breathing. This mechanism may, of course, be supported by autonomic nervous regulation but such factors cannot be analyzed with the technique used by us.

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