VENTILATORY STUDIES OF THE MAXILLARY SINUS

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The gas exchange in the paranasal sinuses is of both theoretical and clinical interest. It is involved in the pathogenesis of sinusitis following ostial obstruction and plays a part in vacuum sinusitis and barotraumatic sinusitis. Most of what is known about gas exchange in the paranasal sinuses is based on the theoretical considerations of Proetz (1953) and on experimental studies on animals by Doiteau (1955) and Flottes et al. (1960). Proetz's discussions on this gas exchange were based principally on the assumption that it was caused by the fluctuations in breathing pressure. Doiteau (1955) and Flottes et al. (1960) investigated the gas exchange in the frontal sinus in the dog by introducing two cannulas into the sinus and connecting them to each other over

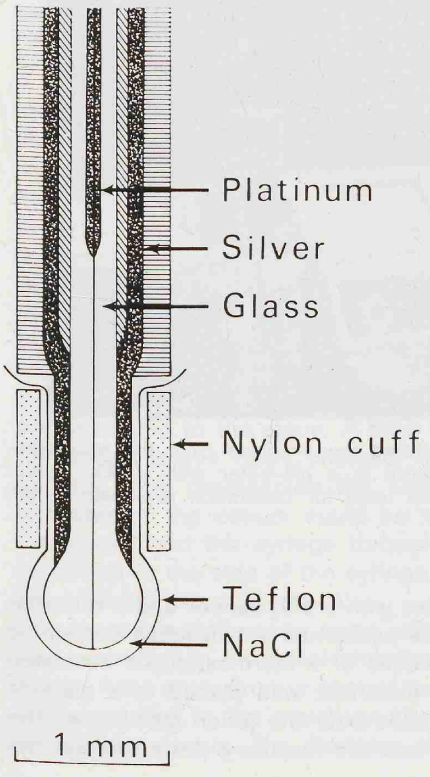

Figure 1. The microelectrode used for pO_2 measurements.

a pump. Samples were pumped from the sinus to a gas analyzer. The procedure altered the conditions of the gas in the sinus completely and the experiment had to be restarted from the beginning after each sampling. These experiments led to the conclusion that the gas exchange in the paranasal sinuses principally was caused by diffusion through the ostium.

Method

For about 2½ years we have made continuous recordings of the oxygen content of the human maxillary sinus under various conditions by using a microelectrode for pO_2 measurements. The electrode is a modification of that described by Meissl and Brotzu (1967). It has a diameter of 1 mm and consists of a glass rod into which a platinum thread is fused (Figure 1). The glass rod, except for its tip, is plated with silver. The platinum thread acts as a cathode and the silver as an anode. The glass tip is covered with a teflon membrane and between the glass and the teflon membrane a drop of saline is placed. A constant, polarizating current is passed through the electrode. Oxygen molecules from the investigated gas pass through the membrane and are reduced at the platinum thread, causing a change in the electric current, proportional to the pO_2 in the gas.

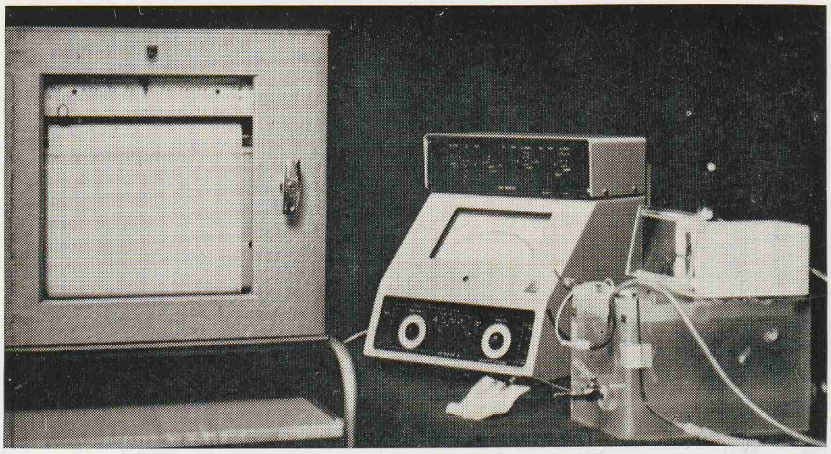

Figure 2. Equipment for measuring and recording the impulses from the microelectrode. The impulses are amplified and measured in a pH-meter with a pO_2 sensor and recorded by a paper recorder. The set-up used for calibration is shown to the right.

The electrode was connected to a pH-meter with a pO_2 sensor and a recorder (Figure 2). Calibration of the electrode was performed in two tubes containing saline kept at constant temperature by means of a thermostat and saturated with nitrogen and air, respectively. The electrode was placed in a cannula with a solid sharp tip and a side hole located over the teflon membrane. The cannula with the electrode was inserted into the maxillary sinus through the

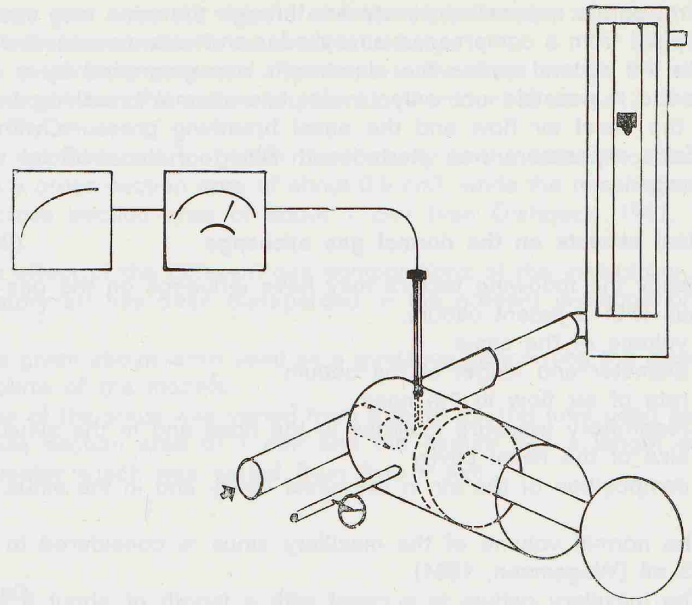

Figure 3. The first model in which a syringe corresponded to the sinus, a tube corresponded to the nasal chamber and the connection between them represented the ostium. The air stream was supplied from a compressed air cylinder and measured with a rotameter. The microelectrode was introduced into the syringe and the gas exchange was measured and recorded by a pH-meter with a pO_2 sensor and recorder.

inferior meatus. Each study was started with recording of the initial oxygen concentration in the sinus. This measurement was followed by exchange of the gas in the sinus for nitrogen in cases with a patent ostium and for air or oxygen in those with an obstructed ostium. One, or sometimes two, other cannulas were inserted into the maxillary sinus for this purpose; one of these cannulas was used for slow insufflation of about 200 ml of the gas. The subsequent changes in the oxygen content of the maxillary sinus caused by gas exchange through the ostium or through the mucosa were recorded by the electrode in the sinus.

Model studies were performed in order to investigate the gas exchange through the ostium. Two different models were used. In the first one a syringe corresponded to the sinus. A tube with a cross section of about 1 cm^2 corresponded to the nasal chamber, and the connection between the syringe and the tube represented the ostium. The volume of the syringe and the diameter of the ostium could be varied. The electrode in its cannula was introduced into the syringe through an airtight membrane, and a thin tube cemented to the side of the syringe was used for insufflation of nitrogen into the artificial sinus (Figure 3).

The second model was in some respects similar to the first one, but the tube corresponding to the nasal chamber was replaced by a rubber model of the human nose made from a cast of the nasal cavities of a cadaver. The syringe corresponding to the maxillary sinus was connected to the nasal model in the middle meatus. The diameter of the connection could be varied.

In the first series a constant air stream through the nose was used. The air was supplied from a compressed air cylinder and was measured with a rotameter. In the second series the air stream was generated by a respirator, which made it possible not only to simulate normal breathing but also to change the nasal air flow and the nasal breathing pressure within certain limits. Each experiment was started with filling of the artificial sinus with pure nitrogen.

Theoretical aspects on the normal gas exchange

Theoretically the following factors may have influence on the gas exchange in a sinus with a patent ostium.

1. The volume of the sinus
2. The diameter and length of the ostium
3. The rate of air flow in the nose
4. The respiratory pressure changes in the nose and in the sinus
5. The size of the nasal cavity
6. The composition of the air in the nasal cavity and in the sinus.

Ad 1. The normal volume of the maxillary sinus is considered to be about 15 ml (Wagemann, 1964).

Ad 2. The maxillary ostium is a canal with a length of about 6 mm and a diameter measured on specimens, of 1-6 mm (Myersson, 1932, Wagemann, 1964).

Ad 3. A tidal volume of 500 ml and a respiratory frequency of 16 breaths per

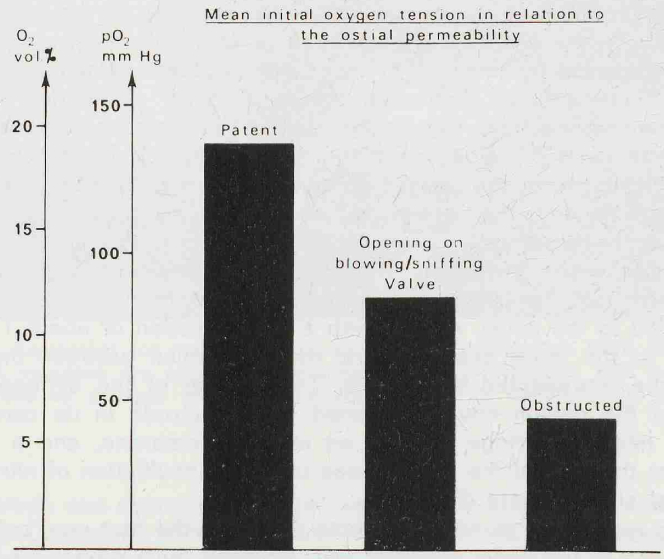

Figure 4. Mean values of the initial antral pO_2 in relation to the patency of the maxillary ostium in normal persons and in patients with sinusitis. The ostial patency was studied by simultaneous recordings of the nasal and antral pressure during breathing, sniffing and blowing.

minute give a minute volume of 8 litres per minute, and approximately 4 litres per minute for each nasal cavity.

Ad 4. The respiratory pressure alterations in the nose and in the sinus are identical when the ostium is patent and amount to about ± 5 to ± 10 mm H_2O.

Ad 5. The narrowest part of each nasal cavity is the internal ostium which has a cross section area of about 0.5 cm^2, while the nasal opening has a cross section area of about 1 cm^2 (van Dishoeck, 1957, Fischer, 1969).

Ad 6. The effect of the different gas compositions of the inspiratory and expiratory air has been disregarded in the present investigation.

The values given above were used as a guidance concerning the sizes of the different parts of the models.
The volume of the sinus was varied from 5 to 15 ml, the tube used as a nose had a cross section area of 1 cm^2 and the ostium had a length of 6 mm and a diameter which was varied from 2 to 6 mm.

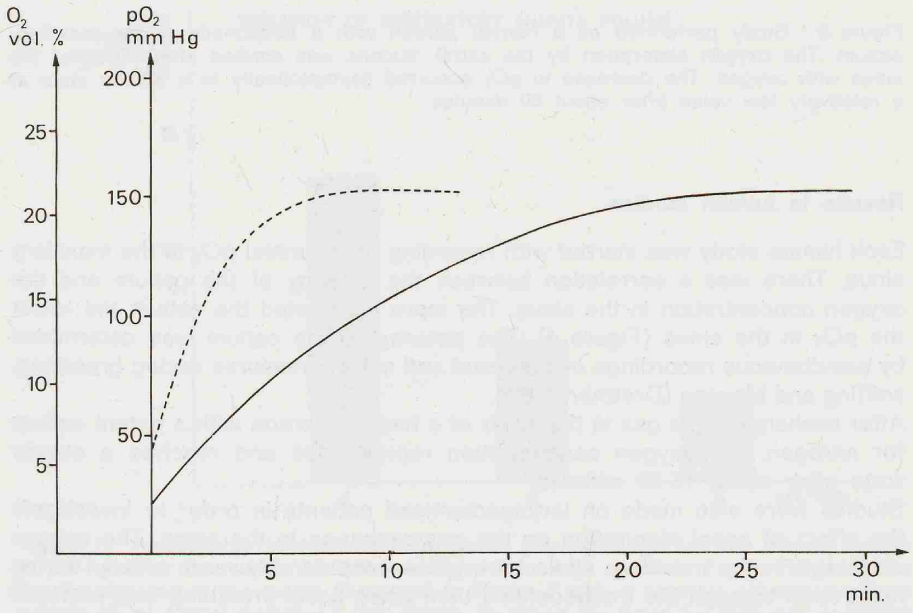

Figure 5. The effect of nasal respiration on the antral gas exchange was studied in a patient who had undergone laryngectomy. The solid curve shows the gas exchange in the maxillary sinus when the patient was breathing through the tracheostoma. The dotted curve shows the gas exchange in the sinus during nasal breathing. Nasal breathing was achieved by means of a tube between the tracheostoma and the nostril on the same side as the investigated sinus. The inspiratory air flow took place through the mouth, via the nasopharynx outwards through the nose, and via the tube to the tracheostoma, while the expiratory air flow had the opposite direction. The patient had difficulties in establishing breathing with a tube passing from the stoma to the mouth.

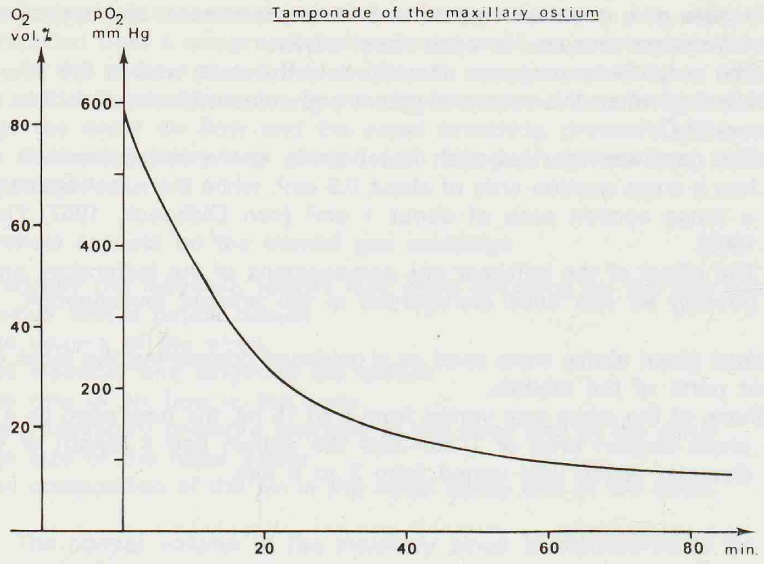

Figure 6. Study performed on a normal person with a tamponade in the maxillary ostium. The oxygen absorption by the antral mucosa was studied after filling of the sinus with oxygen. The decrease in pO_2 occurred asymptotically to a steady state at a relatively low value after about 80 minutes.

Results in human studies

Each human study was started with recording of the initial pO_2 in the maxillary sinus. There was a correlation between the patency of the ostium and the oxygen concentration in the sinus. The more obstructed the ostium the lower the pO_2 in the sinus (Figure 4). The patency of the ostium was determined by simultaneous recordings of the nasal and antral pressures during breathing, sniffing and blowing (Drettner, 1965).

After exchanging the gas in the sinus of a healthy person with a patent ostium for nitrogen, the oxygen concentration rapidly rose and reached a steady state after about 15-50 minutes.

Studies were also made on laryngectomized patients in order to investigate the effect of nasal respiration on the gas exchange in the sinus. The oxygen exchange in the maxillary sinus took place considerably more slowly during respiration through the tracheostoma than when nasal breathing was restored by means of a rubber tube leading from the tracheostoma to the nasal opening (Figure 5).

The normal absorption of oxygen by the antral mucosa was studied in a normal person in whom the maxillary ostium was blocked by a tamponade. The sinus was initially filled with oxygen. The oxygen concentration decreased asymptotically and reached a steady state at a rather low value after about 80 minutes (Figure 6).

Studies on patients with sinusitis and spontaneously obstructed ostia showed

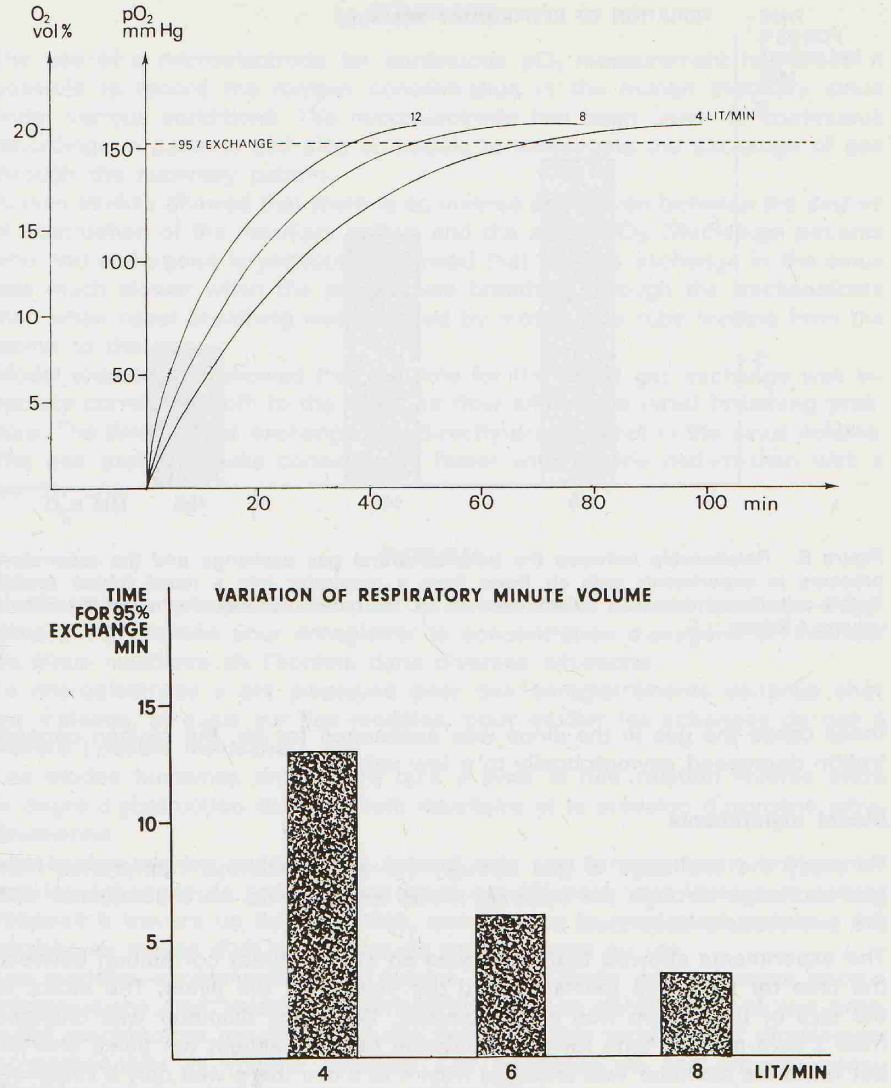

Figure 7. Relationship between time for antral gas exchange and the minute volume of the nasal air flow while the other variables were kept constant. Figure 7a shows the results obtained in the model illustrated in Figure 3 with a constant air stream. Sinus volume 15 ml. Ostial diameter 2 mm. Figure 7b shows the times for 95% gas exchange with fluctuating nasal air flow, generated by a respirator and a rubber model of the nasal cavity. Sinus volume 15 ml. Ostial diameter 4 mm. Respiratory pressure ± 30 mm H_2O.

that the initial oxygen concentration was low in all cases due to absorption of oxygen through the mucosa, and possibly also due to oxygen consumption by the white blood corpuscles and the bacteria in the antral pus. When in

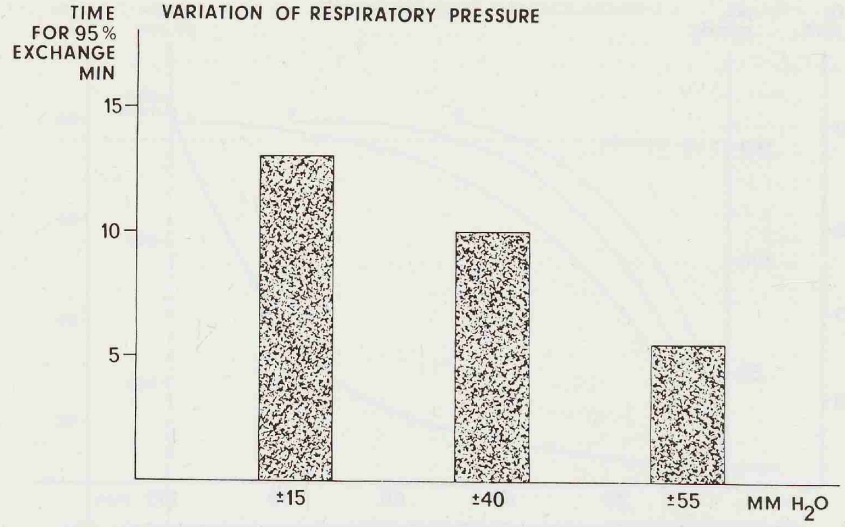

Figure 8. Relationship between the time for antral gas exchange and the respiratory pressure in experiments with air flows from a respirator into a nasal rubber model. In this experiment the sinus volume was 15 ml, the ostial diameter 4 mm and the minute volume 4 lit/min.

these cases the gas in the sinus was exchanged for air, the oxygen concentration decreased asymptotically to a low value.

Model experiments

To study the exchange of gas through the ostium without interference from gas exchange through the mucosa, model experiments were conducted with the two models described.

The experiments showed that there was an almost direct correlation between the time for 95% gas exchange and the volume of the sinus. The effect of the size of the ostium was more complex. When the diameter was changed from 2 to 4 mm the time for gas exchange became almost ten times shorter, but when the diameter was changed from 4 to 6 mm there was only a relatively small difference in the gas exchange time.

In experiments with both models and with both types of air stream the time for gas exchange was almost inversely proportional to the minute volume of the nasal air flow (Figure 7). When the respirator was used for generating the air streams the nasal pressure could be varied. The experiments with the model showed an almost inverse correlation between the time for gas exchange and the respiratory pressure when all other variables were kept constant (Figure 8).

The experiments show that the gas exchange in the paranasal sinus is dependent upon several different factors and it is thus considerably more complicated than previously supposed.

SUMMARY

The use of a microelectrode for continuous pO_2 measurement has made it possible to record the oxygen concentration in the human maxillary sinus under various conditions. The microelectrode has been used for continuous recordings in patients and also in models to investigate the exchange of gas through the maxillary ostium.

Human studies showed that there is an inverse correlation between the degree of obstruction of the maxillary ostium and the antral pO_2. Studies on patients who had undergone laryngectomy showed that the gas exchange in the sinus was much slower when the patient was breathing through the tracheostoma than when nasal breathing was restored by means of a tube leading from the stoma to the nose.

Model experiments showed that the time for the antral gas exchange was inversely correlated both to the nasal air flow and to the nasal breathing pressure. The time for gas exchange was directly proportional to the sinus volume. The gas exchange was considerably faster with a wide ostium than with a narrow one.

RÉSUMÉ

L'utilisation de microélectrode pour la mesure de la pression partielle d'oxygène a été réalisée pour enregistrer la concentration d'oxygène à l'intérieur du sinus maxillaire de l'homme dans diverses situations.

La microélectrode a été employée pour des enregistrements continus chez les malades, et aussi sur des modèles, pour étudier les échanges de gaz à travers l'ostium maxillaire.

Les études humaines ont montré qu'il y avait là une relation inverse entre le degré d'obstruction dans l'ostium maxillaire et la pression d'oxygène intrasinusienne.

Les études sur les malades qui avaient subi une laryngectomie ont montré que les échanges de gaz dans les sinus ont été plus lents lorsque le patient respirait à travers un trachéostome, que lorsque la respiration nasale a été rétablie au moyen d'un tube allant du trachéostome au nez.

Les modèles expérimentaux ont montré que la durée des échanges gazeux intrasinusiens était inversement proportionnelle au débit nasal, et aux pressions respiratoires nasales. La durée des échanges gazeux était directement proportionnelle au volume sinusien. Les échanges de gaz ont été considérablement plus rapides avec un ostium large.

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