Rhinology, XVI, 11–18, 1978

Measurement of air flow in the maxillary sinus by hot-film technique

K. Müsebeck and H. Rosenberg, Kaiserslautern, West-Germany

SUMMARY

A method of hot-film-anemometry was developed to investigate the velocity of air flow in the maxillary sinus which has hitherto not been detected by other methods. The hot-film-probe can registrate the slow but rapidly changing air flow dependent on the respiratory cycles. This study was performed during sinuscopy. The average of measurement values by quiet respiration was found in the sinus of 8 cm/sec during a velocity in the nose of 5 m/sec. The respiratory fluctuations in the nose induce a movement stream of circulation in the sinus. When inspiration changes to expiration there was still a flow but at a lower degree. No flow in the sinus could be observed between respiratory cycles. After sniffing the velocity peak rises to higher values. The air flow in the sinus depends on the patency of the ostium. In case of a reduced air flow we can distinguish between a partially open ostia and an obstructed one. The measurement demonstrates an injector-effect beside the influence of pressure difference and diffusion on the ventilation of the sinus.

Experimental and clinical studies from Doiteau (1955), Flottes (1960), Aust and Drettner (1971, 1974) revealed that the gas exchange between nose and sinus maxillaris is regulated by diffusion through the ostium. According to Proetz (1953) the gas exchange is very slow and caused by the fluctuations in breathing pressure. This led Proetz and Kortekangas (1977) to the assumption that in the sinus there is no significant air flow. Following these and other studies in the literature there is no answer to the question: Does a circulation of air flow occur in the sinus or not? We used the hot-film anemometry and found a remarkable air flow that we are going to report about.

METHODS

In the sinus maxillaris can be expected a low but rapidly changing air flow.

Paper presented at the 2nd Symposium "Medizin-Natur- und Ingenieurwissenschaften", Universität Kaiserslautern, West-Germany, May 13, 1977.

Therefore, it requires a highly sensible equipment to registrate movements of air in the sinus. For this purpose we used a hot-film probe of the type DISA 55 R 42 following the principle of hot-wire-anemometry (Ling, 1960, Almquist and Legath, 1965). In a previous paper (Müsebeck and Rosenberg, 1975) we had described a method of measurement of air flow in the nose by hot wire method. The hot wire probe contains a small wire of wolfram between two pins heated to $T_N = 120°$ Celsius. The heat-loss by air flow destinates the value of velocity according to standardization. The difference in temperature between in- and expiration is negligible (max. 3%).

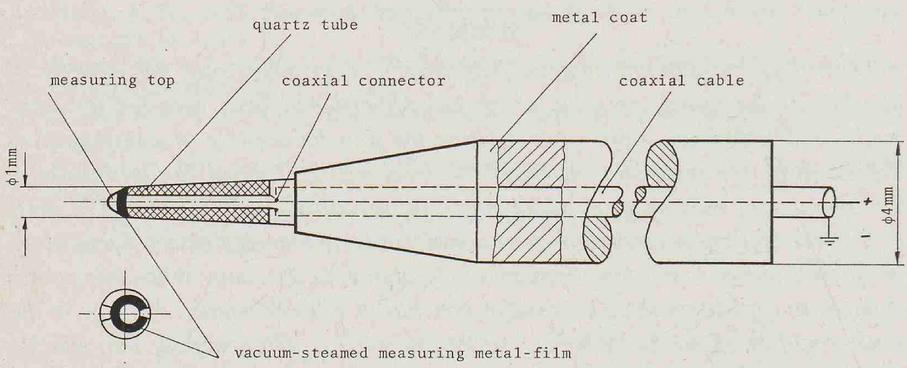

Figure 1. The hot-film probe.

The hot-film probe (Figure 1) as opposed to the hot-wire is covered with a vacuum-steamed nickel film (0,5 mm) on the top of a quartz tube. The small measuring top has a diameter of 1,4 mm × 0,2 mm. This technical condition provides a great frequency response and an intense sensibility to low velocities of only very few cm/sec. Further technical details are given in Figure 1. The quartz tube protects the coaxial connector in the sinus. The metal coat is adapted to the size of the trocar (4 mm). The electronic equipment consists of a coaxial cable, the anemometer with linearisator and of an *y-t*-recorder.
At each examination the sinus was punctured through the fossa canina with a Storz-trocar. The hot-film probe was introduced through this trocar (Figure 2).
During the usual research of the sinus by sinuscopy we can place the hot-film probe by optic control with the Hopkins-optic, for example near the ostium maxillare or at a greater distance from this. The optic control enables us to avoid failure such as contacting the wall or covering it by mucous. In our experiments we have compared the measurement of air flow in the sinus with the respiratory pressure fluctuations recorded by the strain-gauges. The technique was adapted to the equipment of Kortekangas (1977). It includes the

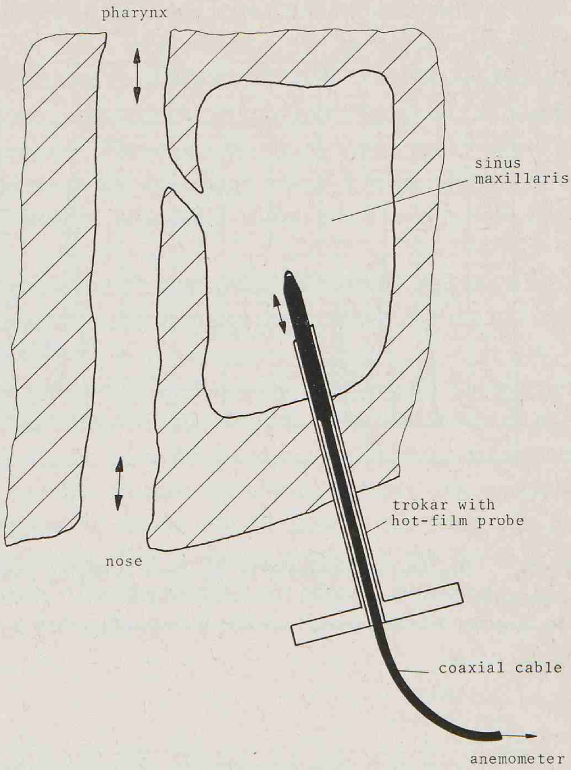

Figure 2. The hot-film probe introduced into the sinus by trocar.

recordings of the reference pressure between nose and sinus and the difference pressure between the sinus and the atmospheric pressure. The compared results will be reported in a further publication.

RESULTS

The air flow conditions were examined in the sinus of thirty patients with maxillary sinusitis in the ENT-Department Kaiserslautern. Figure 3 shows an example of a normal air condition. During inspiration the velocity rises to an increased value in a very short time. The change to expiration is marked by a little gap. The peak of expiration is lower than in inspiration. The circulation is not interrupted in the changing phase of inspiration to expiration. The direction of this circulation is not inversed in the center of the sinus. Release of breathing stops the air movement in the sinus.
Forced breathing (Figure 3b) and sniffing (Figure 4b) rises the values of the velocity. The sniffing produces several high peaks (Figure 4b-3). The velocity was about 8 cm/sec during quiet respiration measured in front of the opened ostium (Figure 3.1; 4b-1).

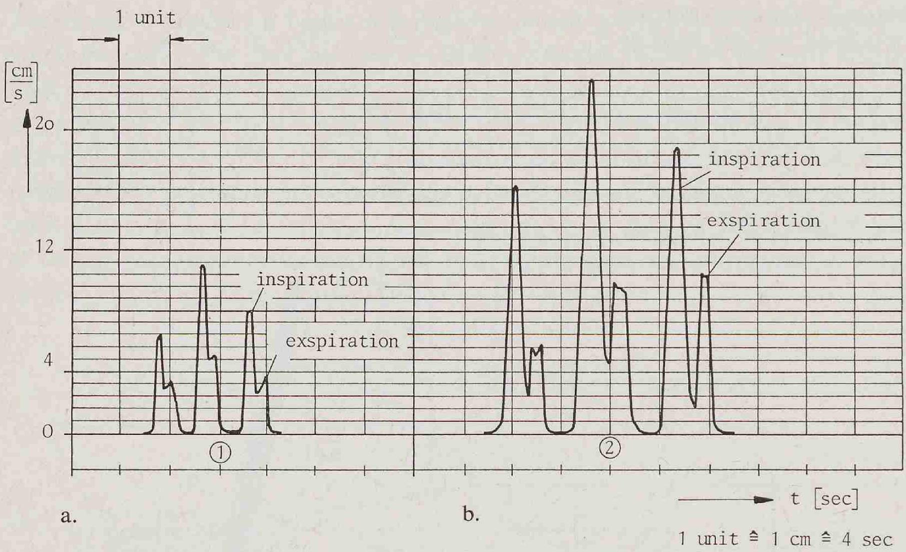

Figure 3. Hot-film anemometry in the sinus 1) during quiet respiration and 2) after forced respiration.
The diagram indicates greater velocity in inspiration than in expiration.

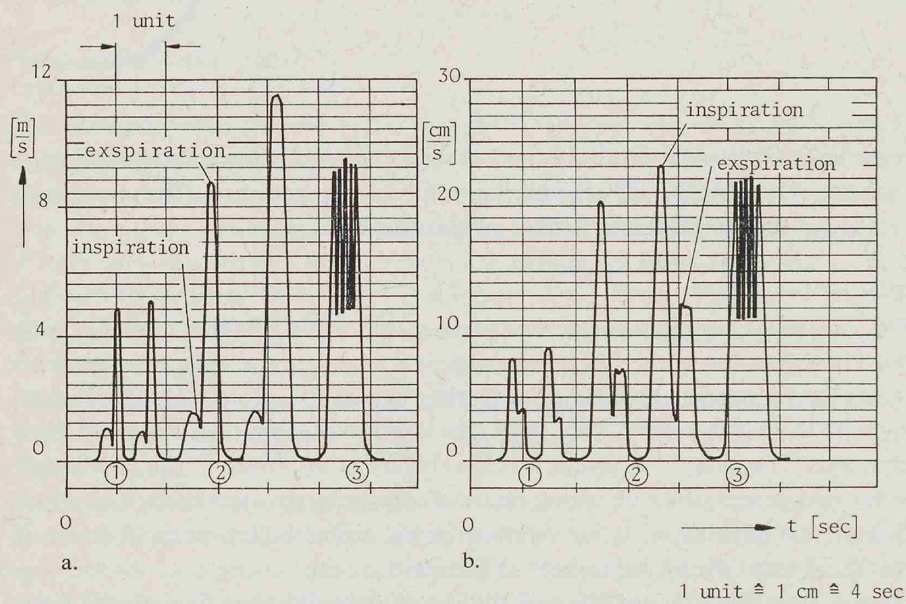

Figure 4. Measurement of velocity a) in the nose, b) in the sinus consecutively.
1) quiet respiration, 2) forced respiration and 3) sniffing
In the nose (Figure 4a) the probe was directed against expiration, therefore the values of inspiration are very slow.

The hot-film probe was used for measurements in the nose under similar conditions, but without a trocar. For these measurements the probe was placed in front of and behind the ostium internum of the nasal cavity. The results depend on the direction of the tip of the probe. In the example of Figure 4a the top is directed to the flow of expiration. Therefore the inspiration peaks show a lower level. The registered values in the nose were about 5 m/sec (Figure 4a). The quantitative analysis of velocity revealed a difference between nose and sinus of 1:50 to 1:100.
The velocity in the nose is diminished if Suprarenin was used. Then the diameter of the nasal cavity is elongated by shrinking of the conchae, but the volume of air stream remains constant.
The swollen state of mucous membrane in the nose and around the ostium maxillary causes a partial obstruction of the ostium. The behaviour of the velocity differs in the sinus from the nose. In the sinus the velocity rises after Suprarenin is given and the swollen mucous membrane shrinks. An example for this effect is shown in Figure 5a and b. No air flow in the sinus can be observed if the ostium is obstructed. This is demonstrated on the left side of Figure 5c with the same patient. After Suprarenin no effect is observed.

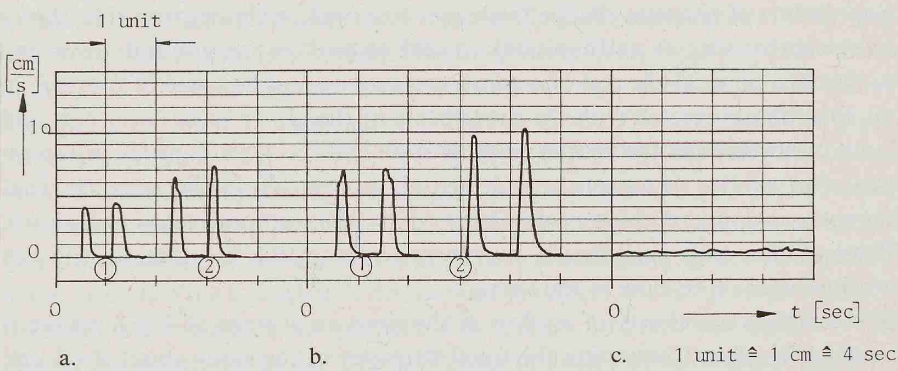

Figure 5. Anemometry in the sinus on the right a) partially open ostium, b) after mucous membrane anesthesia with Suprarenin values increased; left c) no reaction in obstructed ostium; 1) quiet respiration, 2) forced respiration.

The place of the hot-film probe in the sinus maxillaris is important for the recordings. We can control the spot in the sinus with the Hopkins-optic. If the probe is located near the ostium maximal values of velocity are recorded. In the center of the sinus it is more diminished and at the border of the recessus zygomaticus only few peaks are registered on the *y-t*-recorder.

DISCUSSION

The hot-film and hot-wire anemometry has been known since Ling (1960), Almquist and Legath (1965), Andersson (1967) and Miller (1976). We have developed a method by hot-film probe to study the air flow conditions in the sinus maxillary which had not been discovered by other procedure hitherto available. The method is easy to perform when included in the research of sinuscopy.

We know that one respiratory cycle consists of two phases, the in- and expiration. In our studies with the hot-film anemometry the air movements through the ostia maxillaria show four phases during such a cycle. We observed during inspiration that the measured velocity of air in the sinus rises to a peak and converts to a gap. Quite the same two movements of air are observed in expiration, but the peak comes to a lower degree. It is important, that the current of air in the sinus is not interrupted between in- and expiration, however at the end of the respiratory cycle it can be.

The four phases of the movement of air in the ostia have already been postulated since Proetz (1953) and since Badré and Guillerm (1960). Their theoretical aspects and model experiments are based on the pressure changes dependent on the respiratory fluctuation. The inspiration causes a negative pressure difference in the sinus and expiration a positive one against atmospheric pressure. Four points of pressure change from zero to a peak on the negative side, then a zero point between in- and expiration, a peak on positive pressure and converting to the zero point at the end of expiration. Increase and decrease of pressure in the four phases related with the movements of the air. It leads to an out- and input of air through the ostium in inspiration and the same happens in expiration. Our studies demonstrate such periods by measuring the velocity. That supports the theoretical aspects discussed by the authors mentioned above. These authors only supposed it, but we can confirm this assumption with our measurement of air flow in the sinus.

In the registered velocity of air flow in the sinus an average of $V = 8$ cm/sec is remarkably high. Comparing the usual diameter of the sinus about $d = 5$ cm, we believe this high velocity is caused by circulation. The observation, that the speed is not interrupted between in- and expiration supports the assumption of a circulating effect in one direction. Further investigations are required to find the direction of the circulation.

One further question is, what time does the complete exchange of air in the sinus require? According to Proetz (1953) the exchange needs one hour. His theoretical consideration is based on the fact that the pressure difference of $p = 10$ mmgHg combined with an average diameter of 3 mm of the maxillary ostium allows only a minimal velocity during respiratory cycle. One thousand respiratory cycles in one hour are necessary to completely exchange air in the sinus.

Aust and Drettner (1971, 1974) investigated the antral pO_2 under conditions with a wide and with narrowed size of the ostium. They reported that the time for 95% exchange needs between 5–20 minutes depending on several different factors. The gas exchange in the sinus was correlated to the patency of the ostium (Drettner 1974).

Our opinion is, that the exchange of air in the sinus is influenced not only by pressure difference and diffusion, but also by an injector-effect. We can compare this effect with the principle of a water-vacuum-pump. The angle between ostium and nose destinates the size of the air-stream and the value of circulation.

The diagnostic procedure of sinuscopy can be supplied by the method of hot-film anemometry. The method has the advantage that the point of measurement is placed only in the sinus. As opposed to pressure-measurements no extra-antral point of measurement is necessary when applying hot-film anemometry. Therefore the last method is evidently more precise.

ZUSAMMENFASSUNG

Eine Methode der Heissfilmanemometrie wurde entwickelt, um die Geschwindigkeit der Luftströmung in der Kieferhöhle zu untersuchen. Diese Untersuchung war mit anderen Methoden bisher nicht möglich gewesen. Die Heissfilmsonde kann schwache aber rasch wechselnde Luftströmungen in Abhängigkeit vom Atemzyklus registrieren. Diese Untersuchung wurde während der Sinuskopie durchgeführt. Bei Ruhe-Atmung betrugen die durchschnittlichen Messwerte im Sinus 8 cm/sec., in der Nase 5 m/sec. Die atmungsabhängigen Strömungen in der Nase verursachen in der Kieferhöhle eine Luftzirkulation. Beim Wechsel von Inspiration zu Exspiration war noch eine geringe Strömung vorhanden, nicht aber zwischen den Atemcyclen. Nach Schnüffeln steigt die Geschwindigkeit auf höhere Werte an. Die Luftströmung in der Kieferhöhle hängt von der Durchgängigkeit des Ostium maxillare ab. Bei reduzierter Luftströmung unterscheiden wir partielle von totalen Stenosen des Ostiums. Die Messungen zeigen neben der Druckdifferenz und der Diffusion einen Injektor-Effekt auf die Ventilation der Kieferhöhle.

REFERENCES

1. Almquist, P., Legath, E., 1965: Der Hitzdraht-Anemometer bei niedrigen Strömungsgeschwindigkeiten der Luft. DISA-Information Nr. 2/7.
2. Andersen, O. K., 1967: Zeitliches Auflösungsvermögen bei Korrelationsmessungen mit dem Hitzdraht- und Heissfilm-Anemometer.
3. Aust, R., Drettner, B., 1971: Ventilatory studies of the maxillary sinus. Rhinol. 9, 69; 1974: The functional size of the human maxillary ostium in vivo. Acta oto-laryng. 78, 432.
4. Badré, H., Guillerm, R., 1960: La ventilation sinusienne In: La Physiologie des Sinus. H. Flottes et al, Librairie Arnette, Paris, 211.

5. Doiteau, R. J., 1955: Contribution à l'étude de la physiologie des sinus de la face. Imprimerie Sammarcelli Frères, Bordeaux.
6. Flottes, C., Clerc, P., Riu, R., Devilla, F., 1960: La physiologie des sinus. Librairie Arnette, Paris.
7. Kortekangas, A. E., 1977: Funktion und Funktionsprüfung der Nase und der Nebenhöhlen. In: Hals-Nase-Ohren-Heilkunde in Praxis und Klinik. Berendes, J., Link, R. und Zöllner, F., Bd. I, Georg-Thieme-Verlag, Stuttgart 2, 23.
8. Ling, S. C., 1960: Heat transfer characteristics of hot-film sensing elements used in flow measurement. Journal of Basic Engineering, 629.
9. Miller, J. A., 1976: A simple linearized Hot-Wire-Anemometer Journal of fluid engineering, 749.
10. Müsebeck, K., Rosenberg, H., 1976: Nasenfunktionsmessung auf Basis der Hitzdrahtanemometrie und der DMS-Technik. Z. Laryng. Rhinol. 55, 950.
11. Proetz, A. W., 1953: Applied Physiology of the nose. Annals Publishing Company, St. Louis.

Prof. Dr. Dr. K. Müsebeck,
Städt. Hals-Nase-Ohren-Klinik,
6750 Kaiserslautern, West-Germany.

Prof. Dr.-Ing. H. Rosenberg,
Lehrstuhl für Strömungslehre,
Universität Kaiserslautern,
6750 Kaiserslautern, West-Germany.