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Ventilatory effects of the pulse wave in the maxillary sinus

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SUMMARY

The perostial ventilation of the human maxillary sinus is achieved via three main factors: diffusion, respiration wave and the mucosal pulse wave. The ventilatory factors have been studied with the help of a model sinus. The values used in the model are based upon in vivo human studies.

Diffusion is responsible for the most important ventilatory effect in large ostia. Respiration has a ventilatory effect in all ostial sizes. The mucosal pulse has a ventilatory effect when the pulse volume exceeds the dead space of the ostium. When the ostial volume is diminished, the pulse-induced ventilation increases and keeps the total ventilation constant regardless of ostial size. In very small ostia, the mucosal pulse and respiration are the two important ventilatory factors.

HISTORY

The first studies on the size of the maxillary ostium were performed on cadavers. In these studies the ostium is reported to be a canal with a length of 1-22 mm (mean 6 mm) and a diameter of about 1-6 mm (Myerson, 1932; van Alyea, 1936; Simon, 1939; Flottes et al., 1960). The patency of the maxillary ostium could be estimated from pressure registrations in the nasal canal and the maxillary sinus during breathing, blowing and sniffing (Drettner, 1965; Rantanen and Kortekangas, 1971). The functional size of the ostium was calculated from the pressure rise in the sinus when air was insufflated through a canula (Aust and Drettner, 1974). These calculations showed a mean ostial diameter of 2.4 mm. 35% of the functional diameters are less than 1.5 mm.

The mean size of the maxillary sinus measured in cadavers was 10 ml (Flottes et al., 1960). Roentgenographic and manometric measurements showed a sinus volume of 15.8 ml in men and 13.3 ml in women (Aust and Helmius, 1974).

Several authors (Braune and Clasen, 1876; Döderlein, 1932; Kerekes, 1934; Daure, 1943; Drettner, 1961) have reported a pressure wave in the maxillary sinus caused by breathing. In sinuses with experimentally obstructed ostia a pressure wave due to the pulse wave in the mucosa can be demonstrated (Proetz, 1953; Drettner, 1965; Aust, Falck and Svanholm, 1979).

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BACKGROUND

In our in vivo studies of human sinuses we used an EMT 33 pressure transducer and a Mingograph 34 recorder. The pressure transducer was connected to a canula which was introduced through the lower meatus into the sinus after the application of a local anaesthetic. With this equipment we measured the breathing wave in 10 subjects and the pulse wave in another 10 where the ostia of the sinuses had been experimentally occluded.

A Hamilton syringe was connected to the system in order to measure the volume of the maxillary sinus. A small volume of gas was introduced causing a pressure change. The sinus volume, calculated according to Boyle's law, was usually 15–20 ml.

In a sinus with a volume of 15 ml, the mean pressure wave caused by breathing corresponds to a volume of 20 µl (Figure 1) and the pulse wave to one of 4–6 µl (Figure 2).

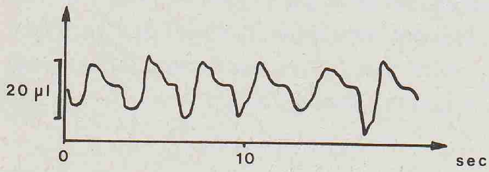


Figure 1. Breathing wave in a maxillary sinus with an open ostium.

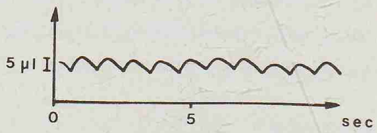


Figure 2. Mucosal pulse produces a pressure wave in a maxillary sinus with a closed ostium.

HYPOTHESIS

The perostial ventilation of the maxillary sinus is brought about in three ways:

1. Diffusion
2. Respiration
3. Mucosal pulse.

MATERIAL AND METHOD

In order to measure the ventilatory effect of the different factors, a model of a sinus in the shape of a small glass bottle was used. A rubber balloon with thick walls was inserted into the bottle and connected to a pulse inducer. The free volume of the bottle was 15 ml. In this model sinus, the pulse inducer produced a pulse wave of 6 microlitres at a frequency of 60/min. Ostia of different sizes could be used and those utilized in this study were (diameter mm–volume µl): 0,40–0,73, 0,5–0,92, 0,75–2,43, 1,0–4,79, 2,5–28,5, 4,0–77,9.

Over the ostium there was a nose model which was connected to an artificial lung, driven by a respirator at a rate of 18 per minute.

The model sinus was filled with oxygen to about 99,0%. The oxygen was bubbled through a basin of water which was kept at a temperature of 26°C (room temperature). The oxygen content of the model sinus was measured with a Perkin Elmer

1100 gas analyser before and during the experiments. The oxygen decrease caused by the different ventilation factors, either separately or in combination, was investigated with different ostial sizes.

RESULTS

The oxygen content of the model decreases asymptotically (Figure 3).
The decrease in the oxygen content is the result of gas exchange through the ostium. The exchange of gas in the model is constant for each separate ostium size and ventilation method (Figure 4).
The gas exchange caused by diffusion increases with ostial size (Figure 3 and 5).
The cumulative ventilatory effect of respiration is an increased exchange in all ostial sizes (Figure 5 and 6).
The pulse wave has a ventilatory effect on ostia with a volume smaller than the pulse, i.e. a diameter of approximately 1.1 mm or less. The ventilation caused by the pulse increases with diminishing ostial sizes (Figure 6). In the smallest ostia, where the pulse has its greatest ventilatory effect, it is of the same magnitude as the ventilatory effect of the respiration.

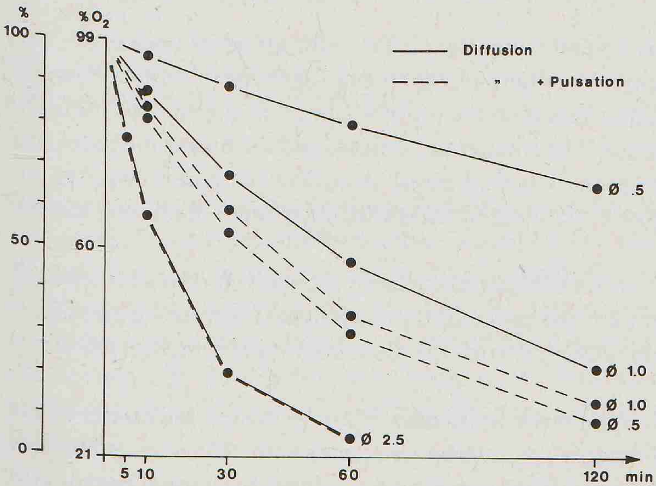


Figure 3.
The oxygen decrease caused by diffusion and diffusion+pulsation for ostial diameters of 0,5 mm, 1,0 mm and 2,5 mm.

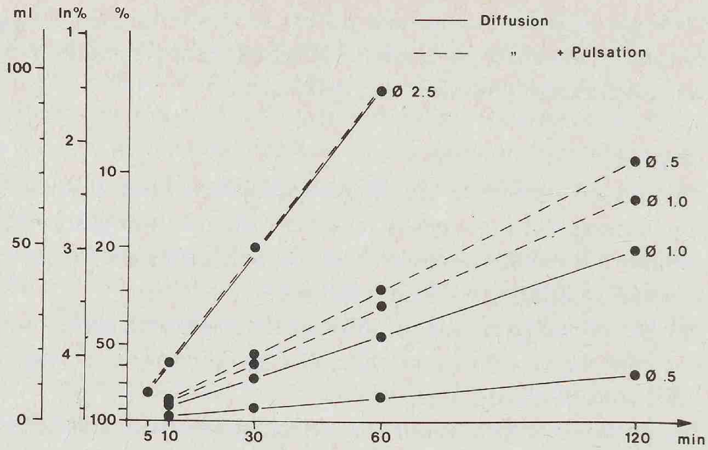
Y-scale:
% O_2 = oxygen content.
% = oxygen content expressed as a percentage of possible oxygen decrease.

DISCUSSION

The gas changes in the maxillary sinus are due to exchange through the ostium, diffusion through the mucosa and cellular and bacterial respiration.
Discussions of gas exchange through the ostium were earlier based upon diffusion and respiration. As shown in this investigation the perostial ventilation of the maxillary sinus is brought about in three ways:

1. Diffusion
2. Respiration
3. Mucosal pulse.

Figure 4.
The oxygen content expressed as a percentage of the possible decrease is transferred into natural logarithms and mirrored, thus giving the ostial gas volume exchange in ml. The straight lines indicate a constant flow.



Diffusion is the major factor in larger ostia. In small ostia, however, it has very little importance.

Normal respiration has a good ventilatory effect with all ostial sizes.

The mucosal pulse pumps a column of gas to and fro in the ostium. When the dead space of the ostium is less than the pulse volume, the pump contributes to the ventilation of the sinus. The smaller the ostium, and the bigger the pulse, the better the mucosal pump. In extremely small ostia, flow resistance acquires importance, but it is unlikely that natural ostia with such small diameters may be kept patent.

Respiration and pulsation are of equal importance as regards for the ventilation of very small ostia. Under pathological conditions, when nasal breathing pressure is diminished, the mucosal pump remains the most important ventilatory factor as regards small ostia.

The cumulative effect of the three ventilatory factors is that in the case of larger ostia (the upper 2/3 of the total), ventilation increases with ostial size. In the case of the smaller 1/3 of the ostia, there occurs a constant gas exchange regardless of ostial size unless the ostium is closed by secretions or oedema.

ZUSAMMENFASSUNG

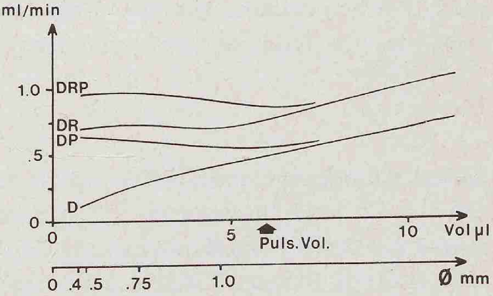
Die Ventilation der menschlichen Nasennebenhöhle durch das Ostium besteht aus drei ventilatorischen Hauptfaktoren: Diffusion, Respirationswelle und Schleimhautpulswelle.

Die ventilatorischen Faktoren wurden an einem Modell der Nasennebenhöhlen untersucht. Die in dem Modell gebrauchten Werte basieren auf menschlichen in vivo-Studien.

Figure 5. Decrease in oxygen content after 10 minutes at ostia of different sizes and with different ventilation methods.
D = Diffusion
DP = Diffusion + Pulsation
DR = Diffusion + Respiration
DRP = Diffusion + Respiration + Pulsation

Diffusion ist der wichtigste ventilatorische Faktor in der grossen Ostien. Respiration hat eine ventilatorische Wirkung bei allen Grössen von Ostien. Der Schleimhautpuls hat eine ventilatorische Wirkung wenn das Pulsvolumen den Totraum des Ostiums überschreitet. Bei Verringerung der ostialen Volumens steigt die durch den Puls bewirkte Ventilation an und hält die totale Ventilation konstant, unabhängig von der Grösse des Ostiums. Bei sehr kleinen Ostien sind der Schleimhautpuls und die Respiration die zwei bedeutenden ventilatorischen Faktoren.

Figure 6. The gas flow noted for the different ventilation methods and related to ostial volumes corresponding to measured ostial diameters.



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