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Experimental studies on the relationship between maxillary sinus ventilation and various obstructions of the nose and nasopharynx

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SUMMARY

The relationship of the nasal and the antral ventilation was studied with a plastinated model of a human nose. The effects of adenoidal hyperplasia and septal deviations on the antral ventilation were measured. It could be demonstrated that the aerodynamic effect of an obstruction within the nasal cavity largely depends on the localisation of the stenosis (anterior or posterior to the maxillary ostium). Additionally, the influence of an ostial obstruction on the antral ventilation was examined in dependence on the nasal ventilation. We were able to demonstrate that the antral pressure variations not only reflect the ostial function but as well the total aerodynamics of the upper respiratory tract. From this point of view we discuss diagnostic and therapeutic conclusions.

INTRODUCTION

Since the discovery of the respiratory pressure variations within the maxillary sinus (Braune and Clasen, 1877) many authors have stressed the pathophysiological importance of the sinus ostium (Drettner, 1965; Rantanen, 1971; Mann, 1979). Only little importance has been attached to the nasal breathing, although the sinus ventilation largely depends on the nasal conductance (Aust and Drettner, 1971; Aust, 1978). In 1932, Proetz investigated for the first time the relationship between septal deviations and pressure variations in the maxillary sinus with technical devices, which were rather simple at that time. From clinical experience we know that obstructions in the nasal cavity are often related to chronic inflammation of the paranasal sinuses. In 1976, Bachmann resumed this idea and stressed the importance of obstructions within the posterior nose section. So far, the indication for septal operations in case of a chronic maxillary sinusitis is generally stated without considering the localisation of the respective obstruction. Therefore, we have investigated the correlation between aerodynamics of sinus ventilation and upper respiratory tract using a true model of the human nose and paranasal sinuses. In particular we studied the effects of adenoids and different positions of septal deviations in relation to the sinus ostium (anterior or posterior positions). Additionally, the influence of the nasal ventilation at an obstructed ostium was studied. The objective of our experiments was to examine our present diagnostic and therapeutic criteria for an operation of the septum in case of a chronic maxillary sinusitis.

MATERIAL AND METHOD

The experiments have been performed on a human nose in natural size, plastinated by a special process (G. v. Hagens) (Figure 1). Obstructions could be inserted in the nasopharynx and septal deviations were imitated by plastics (Optosil®) and inserted to replace the original septum (Bachert, 1986). The maxillary sinus was opened, the ostium could be replaced by canules of different defined diameters. The nose was ventilated by an anaesthetic apparatus (Pulmonat, Fa. Dräger, Lübeck) with a controllable breath frequency and an adjustable flow. We simultaneously measured the pressure along the nasal channel, the nasal flow, the preostial pressure (transseptally) and the pressure within the maxillary sinus itself. In order to achieve comparable results, the respective choanal maximum pressure was kept constant. The measurements were recorded by electromechanical transducers (Rhinotests uP, Fa. Allergopharma, Reinbek) connected to high acceleration writers.

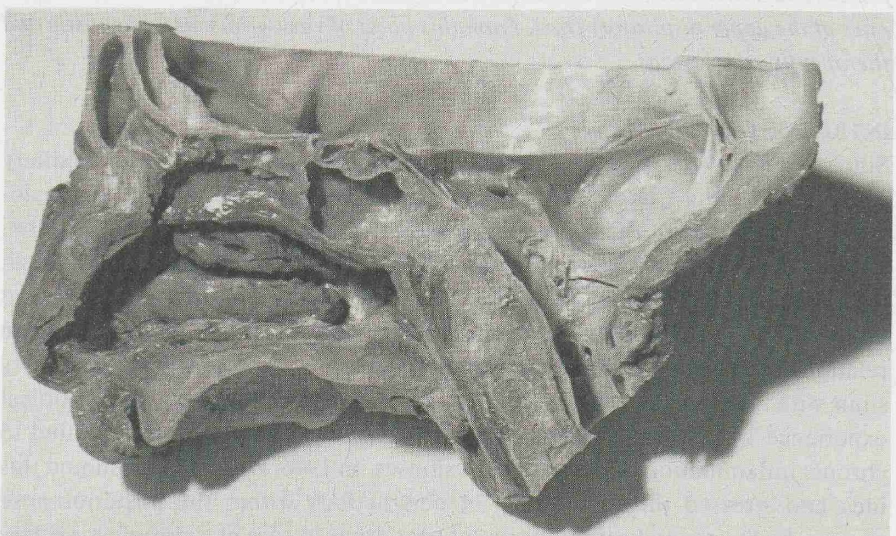

Figure 1. A human nose plastinated by a special process.

nasal obstruction	V_{150}	max. ΔP_a	% Pch/P_a
normal nose	250	250	83
small adenoidal hyperplasia	217	210	70
large adenoidal hyperplasia	134	150	50
posterior spur	183	220	73
posterior ridge	200	210	70
upper septal deviation	217	250	83
anterior ridge	183	240	80
anterior septal deviation	87	290	97
anterior deviation and ridge	117	280	93
vertical deviation	200	280	93
small subluxation	183	290	97
large subluxation	150	300	100

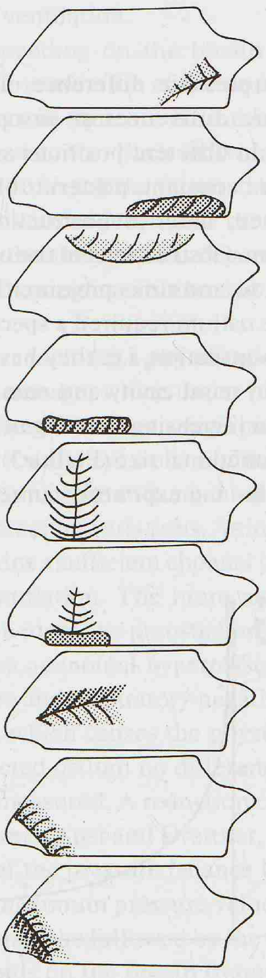

Figure 2. Different obstructions in the nasal cavity an their effect on the antral ventilation. P_{CH} = constant.

First, studies were carried out with adenoids of different sizes and with eleven different septal deviations with regard to each of the five septal areas described by Cottle (1958). Secondly, we varied the size of the maxillary ostium from 7.06 to 0.38 mm^2 (normal values ranging between 4.5 to 5.0 mm^2). During the experiments the pressure in front of the ostium and the corresponding pressure in the sinus were recorded as a linear diagram in order to measure the time-lag of the pressure variations in the sinus with an increasing obstruction of the ostium. Finally, we studied the effect of changes in breath frequency on the antral pressure in case of an obstructed ostium (0,38 mm^2).

RESULTS

The nasal flow values (at a pressure difference of 150 Pascal, V_{150}) and the corresponding antral pressure differences at an open maxillary ostium (7.06 mm^2) with septal deviations in different positions are summarized in Figure 2. Keeping the choanal pressure constant, posterior obstructions (Cottle area 4,5 and nasopharynx) diminished, anterior obstructions (Cottle area 1 and 2) increased the sinus ventilation. Obstructions of the upper part of the septum had less influence on the nasal flow and sinus pressure than those of the lower part. Obstructions posterior to the ostium required a specific size to have a considerable influence on the sinus ventilation, i.e. they have to be equal in size to the isthmus region. At a constant nasal cavity and nasal flow as well as a constant breath frequency we found an increasing time-lag of pressure exchange through the ostium at a diminishing functional size (Figure 3). This became evident by an increasing separation of the in- and expiratory curves (hysteresis) with an ostial size of less than 1 mm^2.

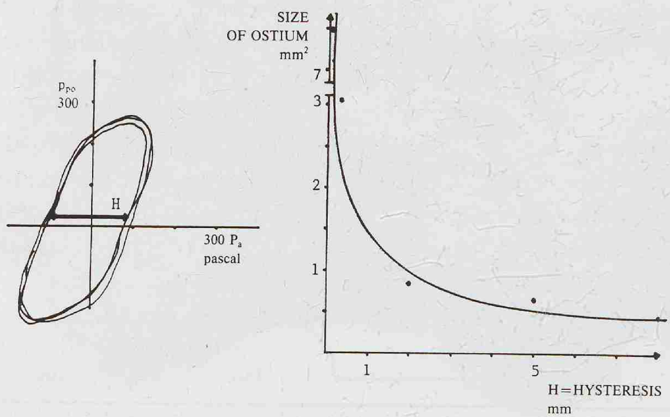

Figure 3. The effect of an increasingly obstructed ostium on the time-lag between preostial and antral pressure. H = hysteresis.

At a severely obstructed ostium (0.38 mm^2 functional size) the dependence of the maximum sinus pressure and the time-lag on the breath frequency and the ventilated nasal flow became evident. The faster the change of in- and expiration, the more evident the time-lag and the more decrease of the antral pressure amplitude, due to a narrowed ostium.

DISCUSSION

The study demonstrates the complex interdependence of the aerodynamics of the upper respiratory tract and the great influence of differently localized obstructions for the sinus ventilation.

The choanal pressure, depending on the breath pressure of the lungs, is of decisive importance for the ventilation of the nose and paranasal sinuses. This pressure can be changed at will (quiet or forced breathing), but strongly correlates with the total nasal resistance. Each individual builds up its own choanal pressure, which is sufficient to reach the required breath flow. As soon as a critical total nasal resistance is exceeded, nasal breathing is replaced by mouth breathing. The pressure at the sinus ostium depends on the choanal pressure as well as an arrangement of the single resistances in the nasal channel of the same side.

Normal anatomy of the nose includes a physiological anterior resistance, i.e. the isthmus nasi. This narrow passage, which under physiological conditions forms about 70% of the nasal resistance, causes a high preostial pressure and therefore provides the conditions for a sufficient sinus ventilation. Additional deviations in the anterior part of the septum cause a stronger isthmus effect and therefore lead to an increase of the sinus pressure variations. As long as the individual continues nasal breathing and maintains a sufficient choanal pressure, these deviations may not diminish the sinus ventilation. The more nasal resistance there is in the posterior nasal channel, the more the preostial pressure decreases. This appears to be especially valid for an adenoidal hyperplasia or posterior spurs or ridges. From an expiratory positive and inspiratory negative preostial pressure results a biphasic sinus ventilation, which causes the physiological gas exchange within the sinus. At a non-obstructed ostium no differences between the preostial and the antral pressure can be measured. A reduction of the size of the antral ostium from approximately 5.00 mm^2 (Aust and Drettner, 1974) to 1 mm^2 and less leads to an increasing time-lag of the pressure balance between nose and sinus. This fact causes a reduction of maximum pressure values in the sinus, the nasal pressure movements can not longer be followed by the antral pressure. Furthermore, the sinus ventilation depends on the breath frequency in case of an obstructed ostium. A high frequency would lead to a large dead-space ventilation and therefore to a diminished gas exchange within the sinuses.

From the general gas equation it can be concluded that a variation of the pressure amplitude in the sinus leads to a variation of the exchanged quantity of air. From this we deduce that the recorded antral pressure movements are correlated with the quantity of gas exchange in the sinus, the importance of which has been stressed by various authors (Aust, 1976; Aust and Drettner, 1971; Rantanen and Kortekangas, 1971). However, we have to bear in mind that our experimental model does not consider diffusion effects or aerodynamic movements resulting from differently shaped ostia and surrounding mucosal congestions (Müsebeck and Rosenberg, 1982).

All these studies show that the sinus ventilation is a very complex process. Pressure variations depend on the patient's depth of breath, on the total nasal resistance, on the shape of the respective nasal channel and nasopharynx, on the ostial function and, in case of an obstructed ostium, also on the breath frequency. If there are any septal deviations (e.g. a choanal atresia or stenosis) which lead to a complete or almost complete obstruction of the posterior part of the nose, there will be no or next to no pressure variations even if the ostium itself is completely open. Therefore, the quantity of sinus ventilation can not be deduced from an endoscopic examination of the ostium alone. On the other hand, antral pressure amplitudes reflect the aerodynamics of the total nose and sinus system and are as well not suitable for a grading of the ostial resistance only.

In order to take these complex relations into account, it is necessary to consider the nose and sinus system as a physiological unit. For the evaluation of the influence of a septal deviation on the sinus ventilation, the nose has to be carefully inspected before and after decongestion and rhinomanometrical measurements of both the total nasal resistance and that of each side have to be recorded. The antral pressure amplitudes should be considered in relation to these data. These aerodynamic interconnections should influence our clinical considerations on the pathophysiology of sinusitis as well as other factors like chronic inflammations of the lateral nasal wall, disturbancies of the local immunology or damages to the ciliary function.

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