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Studies of paranasal sinus ventilation by xenon-enhanced dynamic CT

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SUMMARY

A new method to determine ventilation of the paranasal sinuses is presented. After insufflation of pure stable xenon into the sinus system via the nasal cavity the gas wash-out is detected by means of quantitative dynamic computerized tomography. The measured time density curves allow to derive gas exchange parameters for all paranasal sinuses.

We report mean gas exchange times for the maxillary, sphenoidal and frontal sinuses as well as the posterior ethmoidal cells obtained from 17 patient studies. Some clinical examples are discussed in detail.

Compared to existing procedures, xenon-enhanced dynamic CT is the only non-invasive quantitative method to determine ventilation of all paranasal sinuses.

INTRODUCTION

The condition of the paranasal sinuses is mainly influenced by the mucociliary transport, the patency of the ostia, the oxygen exchange and the mucosal blood flow. The ostia are supposed to play the most important role in physiology and pathophysiology of the sinuses (Drettner and Aust, 1977). The history of ventilation studies of the nose and the paranasal sinus system is described by Proetz in his "Essays on the Applied Physiology of the Nose" in 1953. According to his own investigations, it would require hours (more than 1000 respirations) to completely exchange the air in the sinuses. In the last 20 years new knowledge was gained and a variety of very skilled techniques for research have been developed.

All methods reported up to now are based on the insertion of different devices into the sinus cavity via a hole, created in the bony wall. These methods were limited to the accessible maxillary and frontal sinuses, influencing the condition of the system to be measured at the same time.

We developed a new non-invasive technique which is not limited to the anterior sinuses. It is based on the application of modern computerized tomography and a special xenon insufflation technique.

MATERIALS AND METHODS

1. *Xenon techniques*

The aim is to fill the paranasal sinuses with xenon without an invasive procedure

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like sinus puncture, using small amounts of gas only and avoiding the resorption of the atoxic but anesthetic gas (Pittinger et al., 1953) via the lungs. We place a balloon catheter in each nostril and block the airway through the nose by inflating the balloon. Two to three liters of stable xenon are blown into the sinus system through the catheters via the nasal cavity (Figure 1). Aspiration of xenon was avoided by fractioned instillation during breathing breaks. The gas insufflation is completed within a period of about five minutes.
The cost of xenon gas per examination amounts to about 20 US$, based on a price of pure stable xenon of about 8 US$ per liter.

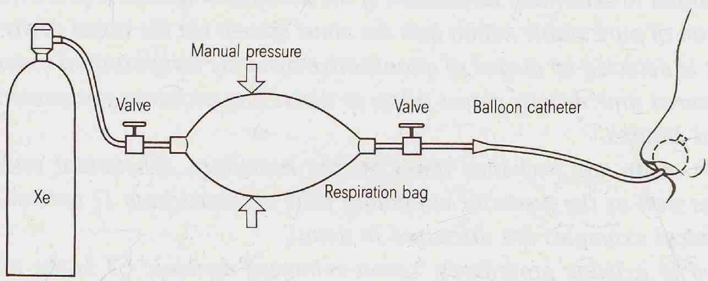


Figure 1. Set-up for xenon application. Two to three liters of stable xenon are insufflated into the paranasal sinus system by manual pressure on a respiration bag via two balloon catheters placed in the nostrils.

2. *CT technique*
The patient is placed supine in the CT unit (SOMATOM DR, Siemens AG), the slice of interest is chosen by a survey radiograph (Topogram). We primarily investigated two planes: one through the superior parts of the maxillary and the sphenoid sinuses and another one through the frontal sinuses, the posterior ethmoidal cells and the sphenoid sinuses.
A series of scans is started about 20 sec after the end of xenon insufflation to allow for removal of the catheters and patient comfort. The decrease of enhancement is measured after the patient resumed normal breathing through the nose. We use seven scans (4 mm slice thickness, 96 kVp, 150 mAs) with an interscan time of 15 sec for the first two, 30 sec for the third and fourth, 60 sec between the next two and 100 sec for the last scan. This sequence allows to monitor xenon wash-out for about 5 minutes. In some cases with apparently slow gas exchange an additional scan is started after another three to four minutes. We routinely obtained an enhancement of 40 to 80, in some cases up to 120 Hounsfield units within the sinuses.

3. *Data evaluation*
The image series are evaluated with standard system software by placing regions

of interest in the selected sinuses, documenting the xenon curves and printing out the enhancement values. These data are fitted to the monoexponential function

$$C(t) = C_0 \cdot e^{-t/t_m}$$

by a separate user-written program. We used the mean gas exchange time t_m [min] to characterize ventilation. Several investigators specified the time $t(90\%)$ after which 90% of the gas in a volume of interest has been exchanged. These values can be compared after a simple conversion:

$$t(90\%) = 2.30\ t_m$$

For further details on the technique see Kalender et al. (1985).

4. *Patient population*

Up to now, 17 patients needing radiological evaluation of their paranasal sinuses prior to surgery of the nose or the ear have been investigated with this method. In order to reduce the effects of variable mucosa thickness on ventilation, nose drops (Xylometazolin) were applied prior to xenon instillation in most of the cases.

RESULTS

A significant xenon enhancement, up to 120 Hounsfield units, was observed in 25 maxillary sinuses, 20 sphenoid sinuses, 7 frontal sinuses and 6 posterior ethmoidal cells. Typical wash-out curves generated by the CT system's evaluation software are shown in Figures 2 and 3.

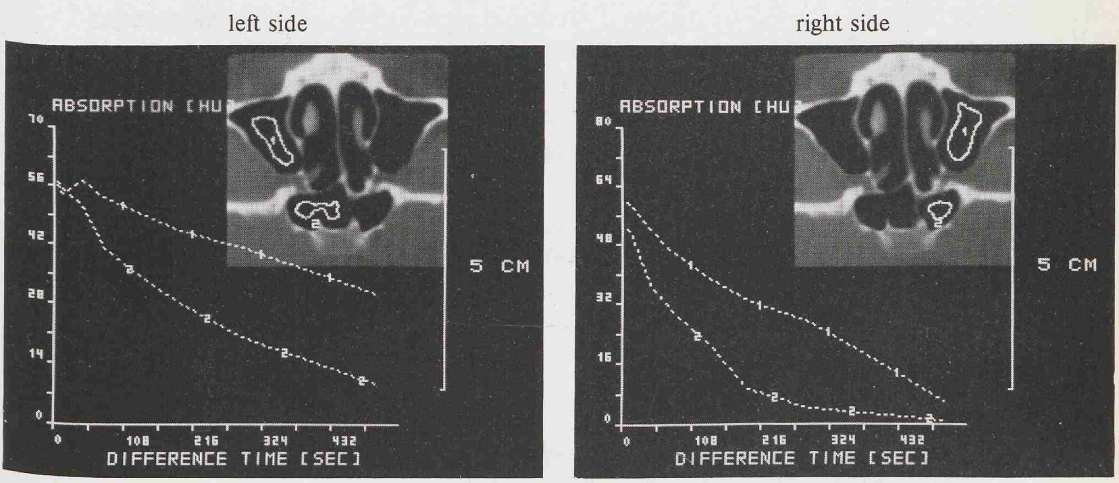


Figure 2. Typical wash-out curves for the maxillary (1) and sphenoid sinuses (2).

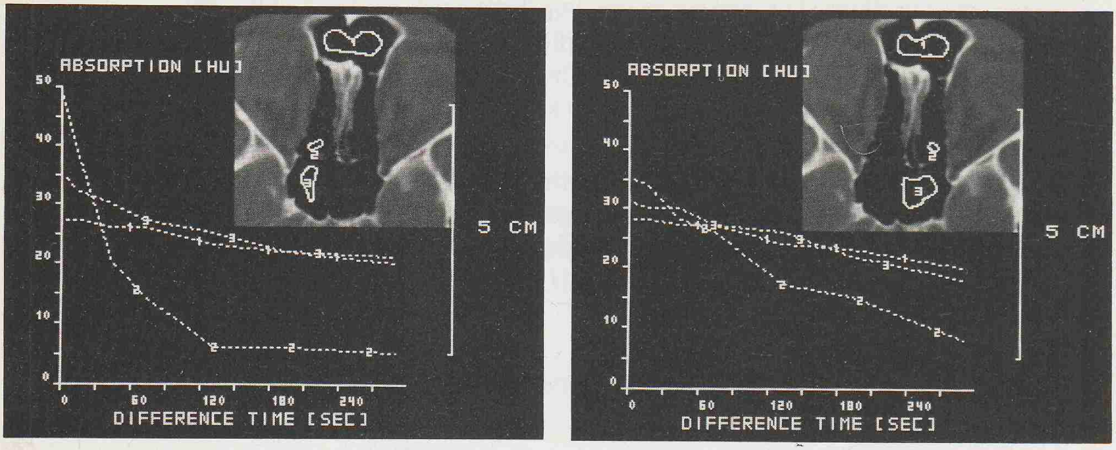


Figure 3. Typical wash-out curves for the frontal (1) and sphenoid sinuses (3) and the posterior ethmoidal cells (2). Note the missing septum between both frontal sinuses.

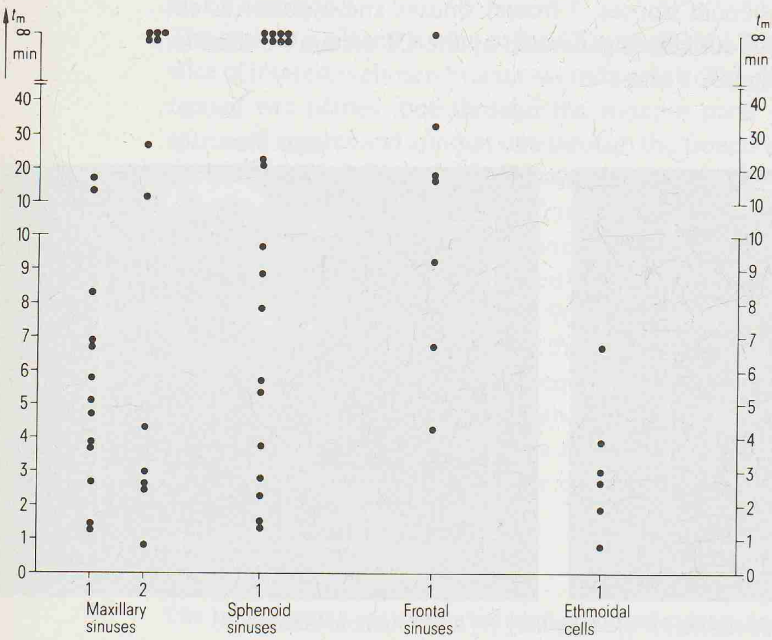


Figure 4. Mean gas exchange times (t_m) of the maxillary sinuses, sphenoid sinuses, frontal sinuses and posterior ethmoidal cells. The values for the maxillary sinuses are divided into a decongestion and non-decongestion group. The values of more than 10 minutes are displayed with different scale. The sinuses without any detectable gas exchange are marked with infinity sign (∞).

1 Xylometazolin application

2 No Xylometazolin application

The calculated mean gas exchange times are presented in Figure 4. For the maxillary sinuses, data are presented for gas exchange with and without mucosa decongestion (in different patients). Most of the values ranged between 1 and 10 minutes with an average t_m of 2.6 minutes in the non-decongestion group and 4.7 minutes in patients with decongested mucosa. Apparently mucosa decongestion does not seem to improve ventilation of sinuses with patent ostium. On the other hand, there were three patients in the non-decongestion group where no wash-out was seen during the entire observation period of up to 10 minutes. After the application of Xylometazolin, however, no more cases with blocked sinus ventilation were detected. The phenomenon of blocked ventilation was more frequent in the sphenoid sinuses (8/20), although the mean gas exchange times in patients with measurable ventilation were comparable to those of the maxillary sinuses (4.9 minutes as an average value for the cases with gas exchange times shorter than 10 minutes).

While the frontal sinuses where rather slow in gas exchange (mean t_m of 14.6 minutes), with only one missing wash-out, the posterior ethmoidal cells showed even faster exchange than the maxillary and sphenoid sinuses (3.2 minutes versus 4.7 and 4.9 minutes). These short exchange times were also found in patients with very slow or even no detectable ventilation of the sphenoid sinuses. Thus ventilation of the posterior ethmoidal cells does not seem to be correlated with the adjacent sinuses.

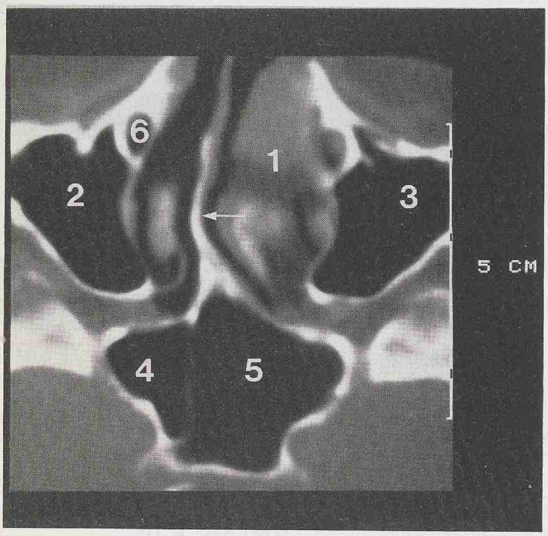
The results reported here were measured in patients without inflammatory changes in the sinuses. Only two patients had mucosa swelling in the maxillary sinuses, resulting in missing or extremely prolonged exchange. Some clinical cases are presented in Figures 5 to 7.

DISCUSSION

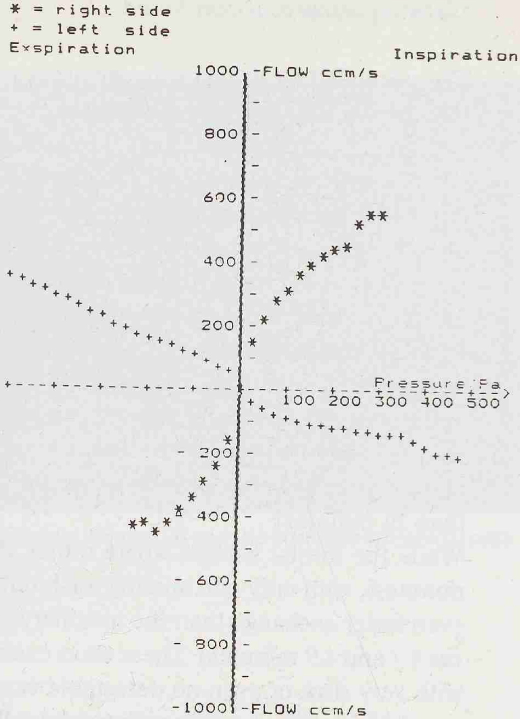
Ventilatory studies of the paranasal sinuses have previously been performed in model experiments (Ivarson et al., 1983; Aust and Drettner, 1974) as well as in human beings and animals (Zippel, 1974, 1979; Streckenbach, 1978; Aust and Drettner, 1971, 1974, 1975). Gas exchange seems to depend on the following parameters (Aust and Drettner, 1974):

- volume of the sinus;
- diameter (functional size) of the ostium;
- nasal air flow;
- nasal respiratory pressure;
- size and shape of the nasal cavity;
- composition of the air;
- gas absorption by the mucosa.

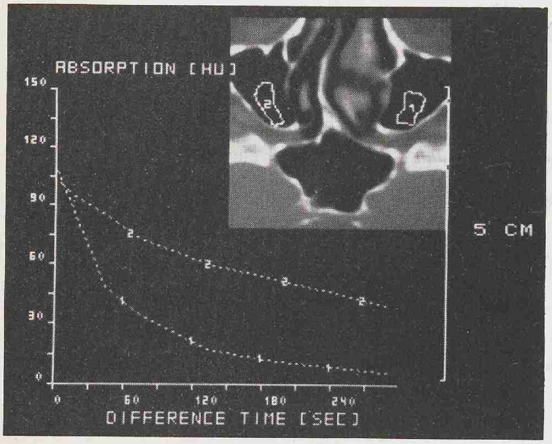
The influence of most of these factors on ventilation of the maxillary sinuses (Aust and Drettner, 1971, 1974, 1975) and frontal sinuses (Zippel 1974, 1979;



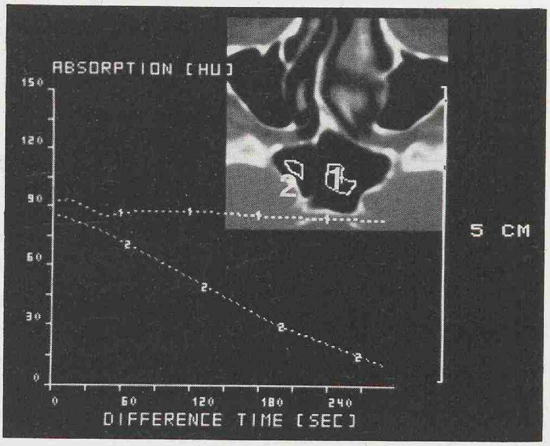
Septal deflection to the left side (⟶) with an enlargement of the right middle turbinate (1). Maxillary sinus left (2) and right (3), sphenoid sinus left (4) and right (5), Lacrimal duct (6).



Results of rhinomanometry: subnormal flow rates on the left side (+).

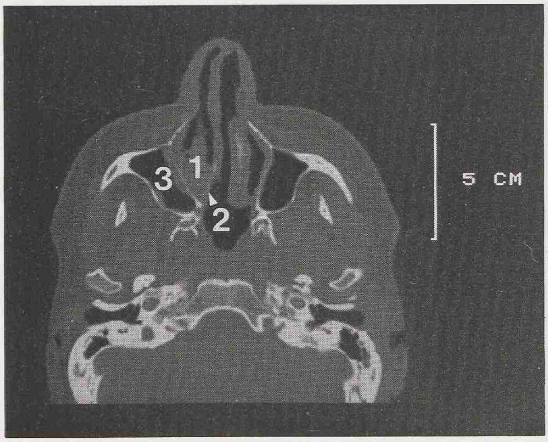


Wash-out curves for the maxillary sinuses: Decreased gas exchange on the left side (2) corresponding to the results of rhinomanometry and explained by the narrow nasal cavity.

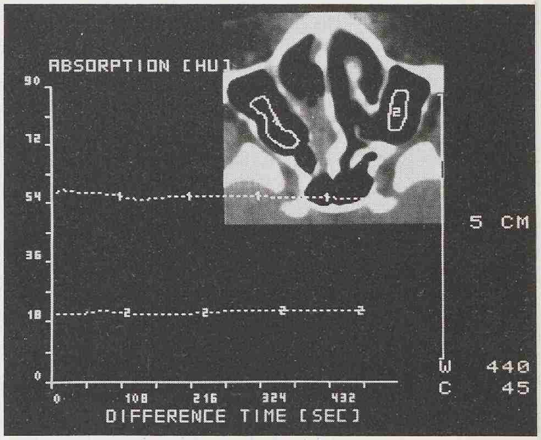


Wash-out curves for the sphenoid sinuses: Rapid wash-out on the left side (2), missing wash-out on the right side (1), presumably caused by the enlarged middle turbinate. No correlation to rhinomanometry.
Note: No inflammatory changes within the sinuses.

Figure 5. Septal deflection



The left nasal airway is completely blocked by mucosa swelling (1) and an osseous plate (2). There is only minor mucosa swelling in the left maxillary sinus (3).



No wash-out is detected in both maxillary sinuses in spite of a free airway on the right side.

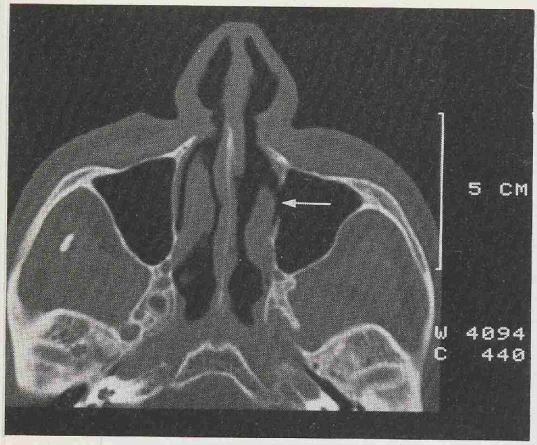
Figure 6. Choanal atresia.

Streckenbach, 1978) were studied. However, all these studies were based on surgical puncture and up to now no evaluation of sphenoid sinuses or ethmoidal cells has been reported.

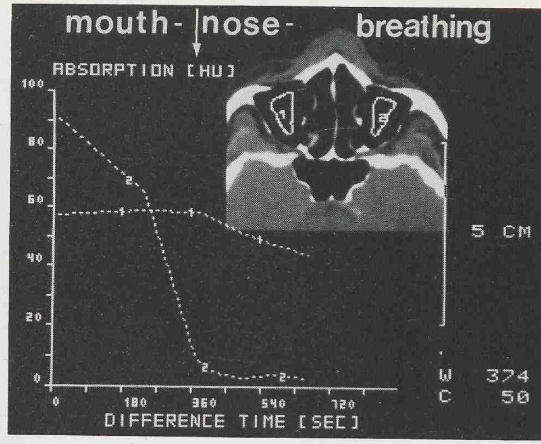
Our results demonstrate the potential of the xenon-enhanced dynamic CT technique for this purpose. The influence of air composition and gas absorption by the mucosa are excluded: since the examinations were carried out in an air-conditioned room, the composition of inhaled air was comparable for all the patients studied. As some cases showed no decrease of xenon concentration within a period of up to 10 minutes, we conclude that absorption of xenon by the mucosa can be neglected. This accords to the findings of other authors who stated that xenon diffuses very slowly into the mucosa (Aust et al., 1978).

The gas exchange of the maxillary sinuses was studied by Aust et al. (1977) and Zippel et al. (1979). They reported *t*(90%) values of about 5 minutes, whereas exchange times of 15 to 50 minutes to reach a steady state after replacing air by nitrogen are presented too (Aust and Drettner, 1971). Our corresponding values are 6 minutes, respectively 10 minutes after the application of Xylometazolin. The tendency of prolonged gas exchange time for the maxillary sinuses after mucosa decongestion can not be explained by our data yet. This discrepancy was not observed in comparable studies (Aust et al., 1979). In patients with a permanent, surgically created window between the nasal cavity and the maxillary sinus, ventilation is very rapid even during mouth-breathing (Figure 7).

Values in the literature for the frontal sinus were 1 to 10 minutes (Zippel et al., 1979). Our results are somewhat higher (26.2 minutes). Normal mean gas ex-

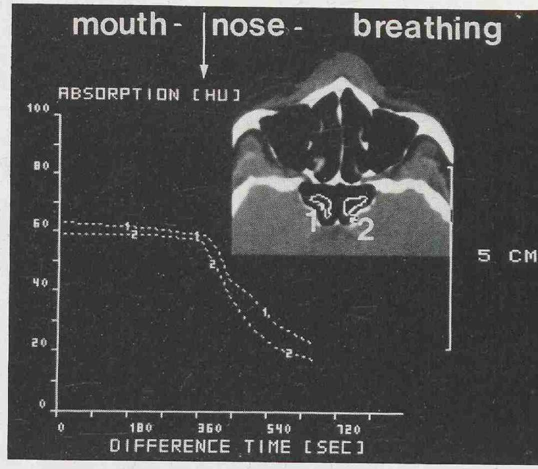


he right maxillary sinus shows a surgically created indow in the inferior meatus (⟶).



Wash-out curves for the maxillary sinuses:
On the left side (1), wash-out is only seen after nose-breathing. The wash-out on the right side with an open window (2) is rapid even during mouth-breathing.

/ash-out curves for the sphenoid sinuses:
here is little wash-out during mouth-breathing and ·gular decrease of the xenon concentration after reathing through the nose. ▶



'igure 7. Difference between mouth-breathing and ose-breathing.

change times for the sphenoid sinuses and the posterior ethmoidal cells under physiologic conditions are presented by this study for the first time.
The complete absence of gas exchange during the observation period of up to 10 minutes occurred very frequently in the sphenoid sinuses, rather seldom in the maxillary sinuses and in the frontal sinuses. This phenomenon was not observed in the ethmoidal cells. We suppose that there are periods of absence of any ventilation, mainly in the sphenoid sinuses, even under physiologic conditions and

without inflammatory consequences. There was also no evidence of sinus pneumoceles as could be expected in the cases where xenon passed the ostium due to the increased pressure (insufflation or Valsalva maneuver), but did not leave the sinus subsequently. The "one-way valve" function of the ostium cannot explain the development of pneumoceles satisfactorily (Wolfensberger, 1984).

CONCLUSIONS

In comparison to previous approaches our dynamic CT method to measure paranasal sinus ventilation by insufflation of stable xenon and measurement of the wash-out has several distinct advantages: It is non-invasive, does not affect the sinus system and it is not limited to the maxillary and frontal sinuses. As both sides can be evaluated simultaneously, a more physiological aspect of the ventilatory function of the sinuses can be achieved. Due to the special xenon insufflation technique and the small amounts used, no significant amount of xenon is absorbed in the lungs and therefore no narcotic side effects can occur. In addition to the functional ventilation analysis, the CT images provide visualization of anatomical details like septal deviations and mucosa diseases. Patient dose is low as we can afford to select low mAs- and kVp-values for this quantitative evaluation. Minor drawbacks of the method consist in the cost of xenon (about 20 US$ per study) and the sensitivity to patient motion. The latter especially affects the evaluation of the smaller sinuses (ethmoidal cells).

ZUSAMMENFASSUNG

Wir berichten über eine neue Methode zur quantitativen Bestimmung des Gasaustausches der Nasennebenhöhlen. Sie beruht auf der computertomographischen Messung des "wash-out" von nicht-radioaktivem Xenon-Gas aus den Nebenhöhlenlumina bei Ruheatmung. Das Gas wird mit Hilfe von Ballon-Kathetern über die Nasenhöhlen in das Nebenhöhlensystem geleitet und die hierdurch hervorgerufene Dichteänderung in ihrem zeitlichen Verlauf durch dynamische Computertomographie bestimmt.

Bislang wurden 17 Patienten untersucht und mittlere Gasaustauschzeiten für Kieferhöhlen, Stirnhöhlen, Keilbeinhöhlen und hintere Siebbeinzellen ermittelt. Im Vergleich zu den aus der Literatur bekannten Werten fanden wir für die Stirnhöhlenventilation deutlich längere Austauschzeiten. Keilbeinhöhlen und Siebbeinzellen wurden mit unserer Methode unter physiologischen Bedingungen erstmals untersucht. Auffallend war eine zumindest temporär völlig fehlende Ventilation der Keilbeinhöhlen, ohne daß dies entzündliche Veränderungen zur Folge hatte. Das vorgestellte Verfahren hat im Vergleich zu bekannten Methoden den Vorteil, daß es nicht invasiv ist und die Belüftung des Untersuchungsgebietes nicht beeinflußt. Es ist außerdem prinzipiell bei allen pneumatisierten Höhlen anwendbar.

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