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AIR CURRENT IN THE NASAL CAVITY
AND FUNCTION OF THE NOSE

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INTRODUCTION

The author had often difficulty to understand contradictions between disorders in the nose and clinical complaints. One meets with cases where a considerable anatomical obstruction gives rise to only a slight obstructed nasal respiration or none whatever; on the other hand, an inconsiderable anatomical obstruction may cause a suprisingly great disturbed function.

When the author six years ago began to occupy himself with the questions regarding this subject, he soon discovered that the physiology of the nasal respiration contains many important problems, none the less interesting because several of them are only incompletely or even not at all clarified.

It is also interesting to see that most of reports dealing with those purely physiological problems were made by foreigners. The reason why these questions were put aside in Japan, seems to lie in the fact that the clinical researches and especially the pathological studies did not rouse the interest of Japanese oto-rhino-laryngologists.

We believe, we can not conscientiously treat any patients, if we lack in the exact knowledge concerning the physiology of the nose. It is important for oto-rhino-laryngologists, indeed, to consider the nasal respiratory function from a wider angle.

There are quite a number of authors who worked on the problem, but

there are few who paid attention to the collective contributions by a complete system in the nasal functions. Unfortunately some of them were misled by derangements within the physiological limits such as natural to any organic system.

From these considerations the author has been convinced that a good knowledge concerning the nasal functions could only be obtained by systematic experiments.

The aim of this paper is to introduce the results in the main obtained in the author's institute. The above-mentioned task which the author proposed to undertake, is, however, so extensive that he naturally can not wish to lay claim to completeness.

SUMMARY

1. Determination of Air Flow in Normal Respiration

The question of the time relation of the respiratory air flow and its pathway through the nasal cavity is of great theoretical interest and most probably of great importance. Before dealing with this problem, we must determine precisely the volume of air passing through the nose in ordinary respiration.

Previous authors assumed from their experiments that air flow averaged 9 liters per minute. They did not, however, pay enough attention to the fact that even during the ordinary breathing the respiratory air flow might be subjected to considerable variations.

We calculated the volume velocity of the air flow from the data of respiration curves for some subjects, as recorded by means of pneumograph. By repeated tests maximum volume could be determined. As a whole, the maximum volume in the expiration phase is estimated at 21.7 to 19.7 liters per minute and the maximum volume in the inspiration phase 23.7 to 26 liters per minute, which represents the average physiological difference of 5.6 to 3.7 liters per minute.

We know that there are slight variations among normal noses, but we were able to find a large reduction of the maximum volume in latent respiratory insufficiency. This fact is ascribed to the fact that the nasal respiratory insufficiency is unconsciously compensated by the oral respiration.

Beside the above mentioned experiment regarding the respiration curve, we measured the maximum volume flow of inspired air in one of the nasal cavity samples by means of thermocouple anemometer. These later results

coincide with those obtained by the earlier experimental procedure and the average value of the maximum volume in inspiration is 10.2 to 15.9 liters per minute and the average value is 13.6 liters per minute.

We can point out that the speed of air flow at certain moments may certainly exceeds 9 liters per minute, the figure given as determined by previous authors, because of the fluctuation of air flow during the respiration. According to our experimental results the maximum volume flow is 13 liters per minute in inspiration and 11 liters per minute in expiration. The value of the air flow as measured by volume flow per minute was a great help to us in the following experimental procedures.

2. Air Pathway in the Nasal Cavity

1) Demonstration of Pathway by Means of Tobacco Smoke

Perusal of the literature dealing with the pathway of air current in the nose, would show how many authors have made reports which were by no means in agreement. It is important that the experiments are based upon conditions encountered in the normal nose. From this point of view we improved the experiments by using human head, replacing the septum with the glass plate and passing tobacco smoke through the nose.

In normal noses ordinary inspired air produces laminary current, passing in the main along a wide curve beginning at the nostril, extending through the anterior part in the middle turbinate, passing through the middle meatus and ending in the choana. Apart from this main current, some of the inspired air follows a pathway along the inferior meatus. If the speed of flow of the inspired air reaches 3 liters per minute, a small eddy is set up in front of the middle turbinate, but it does not influence the main current. This is obviously significant for the sense of smell.

A flow of 13 liters per minute produces eddies in the whole nasal cavity.

Thus the normal nose maintains the laminary air current as long as the speed of air flow is below the critical value of 13 liters per minute.

Many authors made reports regarding the difference of the pathway between the inspired and the expired air but their results as yet differ from each other.

According to our result expiration air returns by the same pathway as it entered in the phase of inspiration. At the moment when the inspiration is reversed to the following expiration, certain eddies are observed to set up at various parts, for example at the anterior margin of the middle turbinate,

posterior part of the inferior turbinate and pharyngeal opening of Eustachian tube.

With regard to the influence upon the nasal obstruction, we examined working on the same principle, how the air current flows through some samples of the pathological nasal cavity. Watching the current through the glass septum it is clearly seen that all pathological changes produce eddy current in various parts in the nasal cavity and the critical speed of flow below which the normal laminary streaming can be maintained is reduced.

We can conclude in these experiments that the inferior turbinate is more important than the middle turbinate for the maintain once of the intranasal laminary current.

An obstruction in the superior meatus and nasopharyngeal region, unless very considerable, did not affect the intranasal air flow.

Therefore it will be clear why pathological changes of the inferior turbinate have a great effect upon the nasal stenosis.

2) Demonstration of Pathway by Means of Dye

The experimental method, to study the pattern produced by tobacco smoke mixed in the inspiration air, is one of the best methods, but it does not reveal delicate details of the pathway. Then we, verifying that a stream of water take the same pathway as an air current through the nasal cavity, immersed the model of nasal chamber set in a pan containing water and studied the current set up in the nose by means of a colored indicator.

To obtain the similar pattern in such different medium, adjustment in Reynold's number is necessary. We can conclude by calculation that a flow of water must be one fifteenth of that of air to reproduce the same pattern as to the pathway in both media.

The results obtained by this model investigations were same as those by the preceding investigation. In the normal nasal cavity turbulences were produced in the whole space when the water volume of flow exceeds 960 cc per minute and at this speed the critical Reynold's number is about 1120. Removal of all the turbinates markedly reduced, the critical Reynold's number. Removing the middle turbinate, the eddy was produced over a flow of 720 cc per minute which corresponds with the critical Reynold's number 830. When we cut off the inferior turbinate eddy currents were seen in a flow of 470 cc per minute. This water flow corresponds to Reynold's number 542.

From this investigation it was made clear that the critical flow of water is 960 cc per minute to maintain the laminary current and its value corresponds

to an air volume of 14.4 liters per minute.

3) Theoretical Consideration of Streaming in the Nose

As above mentioned the inevitable decrease of Reynold's number in the pathological nasal cavity shows a rapid increase of resistance and so it is easily understood that the effect of the turbinates is to maintain the nasal current laminary and why absence of the nasal turbinates introduces the nasal stenosis. Even the majority of authors who studied air flow conditions in the nose did not accurately deal with this problem in physical aspect.

When we assume that the normal respiration does not produce any turbulence in the nasal cavity two-dimensional non-rotatory movement theory can be applied to this problem. The differential equation of a stream line is as follows:

$$\frac{dx}{u} = \frac{dy}{v} \quad \text{or} \quad u \cdot dy - v \cdot dx = 0 \quad (1, 1)$$

Assuming the fluid is incompressible, the equation of continuity can be expressed

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad \text{or} \quad \frac{\partial u}{\partial x} = \frac{\partial (-v)}{\partial y} \quad (1, 2)$$

From Eq. (1, 1) and Eq. (1, 2) we obtain the following equation,

$$u \cdot dy - v \cdot dx = \partial \varphi = \frac{\partial \varphi}{\partial x} \cdot dx + \frac{\partial \varphi}{\partial y} \cdot dy \quad (1, 3) \quad \text{where} \quad u = \frac{\partial \varphi}{\partial y}, \quad v = \frac{\partial \varphi}{\partial x} \quad (1, 4)$$

When φ is known, u and v can be expressed as definite functions. As the equation of a stream line is expressed in (1, 1) it is transferred as follows:

$$\varphi(xy) = \text{const}$$

In case of non-rotatory movement it assumes the form,

$$\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} = 0 \quad (1, 5)$$

If we can obtain the function which satisfies Eq. (1, 5) we can theoretically demonstrate the pathway of the main stream in the nasal cavity.

Assuming that sagittal section of the nasal cavity is a rectangle and the angle between the nasal floor and the axes of the inlet and the outlet is 90° , 45° , or 135° , we can draw the stream line for various initial conditions. As its calibrated results are analogous to that previously stated, we can induce that the respiration obeys to this aerodynamics. But actually the respiratory air is subjected to a frictional resistance from the wall and then the flow of air per minute increases rapidly in the middle meatus where the viscous

friction may be negligible, compared with other regions.

According to this conception, we can conclude that the ordinary breathing produces laminary streaming in whole nasal cavity but actually a lot of air passes through the middle in the nasal cavity due to the little resistance owing to relatively slight viscous friction of the wall, as is demonstrated by a curved pathway in the middle meatus.

3. Air Current Velocity in the Nasal Cavity.

Especially with regard to the form of the air flow in the complicated and variform passages the need of deeper knowledge is called for. We must consider from the co-existence of both laminary and turbulent air-current, that a different distribution of current velocity of air may take place in the nasal cavity. It might be rightly pointed out that in modern literature there are practically no reports concerning this problem.

We employed a heated thermocouple in the measurement of air current velocity, instead of manometer to keep physiological conditions as much as possible, and we worked with a model of natural size made from the cast of a cadaver-nose through which we led the constant air-flow and measured the current velocity at 8 different points in the nose.

In a normal nose the current velocity is reduced in front of the inferior turbinate and again increased in the middle meatus up to more than that which existed in the nostril. The velocity increased a little in the posterior part of the middle and the inferior meatus and it approached a high value at the narrow choana. Starting from this normal model we have undertaken measurements in pathological noses. Removal of the inferior turbinate made the current velocity in the middle meatus decrease which, however, was not proportional to the air flow. We concluded that this is due to formation of eddies in that region.

We observed in the experiment that if the middle turbinate is removed, the current velocity remains unchanged except in the middle meatus where the velocity is decreased. This result may be ascribed to the fact that the removal of the middle turbinate can hardly change the whole air current through the nose.

Removal of the inferior and middle turbinates shows remarkable decrease of the velocity in various places and these decrease are not proportional to the air flow volume.

Hypertrophy of both middle and inferior turbinates bring about an increase

of air current velocity in the middle of the nose.

4. Air Pressure in the Nasal Cavity (Patency of the Nose)

As above mentioned the current velocity in the nasal cavity has an essential relation to the form of the cavity and pathway of the respiratory air. We have to deal with an essential factor here, that is to say loss of energy owing to the resistance in the nasal cavity, which is inversely expressed by the term "patency" of the nose. The patency is reduced when the loss of energy is greater and pressure difference between the inlet and outlet is larger. The most important factors which exert an influence upon the patency of the nose are the effects of vestibule, turbinates and septum.

1) Alae nasi and Nasal Vestibule.

To solve the question of the resistance in the nose, we inserted a catheter in front of the middle turbinate which was connected with a manometer and at the same time a manometer is attached to another side of nostrils by means of an olive and the static pressure is determined during ordinary respiration. By this method we can determine the fall of pressure on the section between the vestibule and the nasopharynx.

From this result we can deduce the resistance in the vestibule but strictly saying we must calculate loss of pressure head by Bernoulli's formula.

It is interesting that the fall of pressure in the vestibule is far greater, especially in the inspiratory phase than we supposed. Although this result appears to be improbable, we are able to state with confidence from a number of experiments on models that changes of air pathway in the vestibule produce a great loss of energy.

2) Expansion of Nostril and Action Current of Muscles of Alae nasi.

We worked to solve the question how to regulate the width of the air passage and to prevent the occurrence of obstruction during deep breathing.

We artificially changed the width of the nostril and measured the static pressure in the nose. The result told us a great deal about the function of muscles of alae nasi. The expansion of the nostril reduces the air flow resistance more than the cocaineization of the nasal mucosa.

With regard to the respiratory movement of alae nasi in dyspnea, we could register the action current produced by the muscular activity. The oscillograms show that the contractions confine themselves to the inspiratory phase.

3. Pressure at Lateral Wall of the Nasal Cavity

It is of great importance to measure the gradient of pressure in the nasal cavity and to determine whether this can be considered normal or whether nasal respiratory insufficiency is the cause, as well as to determine its degree when it is present. Most of the experimental methods are based upon aerodynamic laws. We measured the pressure difference at various places in the model and in different air flow. While determining the pressure we calculate the effective cross-sectional area and also we obtained the reduction rate which expresses the ratio of the effective cross-sectional area in the normal nose to that in a pathological nose.

From these experiments we found that the effective cross section is smaller compared with the actual one in a pathological nose and in atrophic cases a models with a hypernormally wide space paradoxially values below normal. This result corresponds to the fact that patients with atrophic rhinitis complain of obstructed nasal respiration.

As we have spoken of effective cross section and reduction rate of the nose, it is necessary to express theoretically the hardness of the nasal respiration. If we keep the air flow and the time required for passage through the nose constant, the larger the difference between the terminal pressure is, the greater is the nasal obstruction. Therefore the ratio of the pressure difference between nostril and arbitrary position in the normal nose to that of pathological nose can express certainly the degree of hardness of nasal respiration. From our results we know that the values obtained show the proportionality with that of the anatomical obstruction.

We must distinguish the sensation of the nasal obstruction from the patency of the nose. Nasal obstruction usually refers to an aspect of the sensation obtained by air passage in the obstructed nose. We measured the patency in the nose by means of physical instruments. Then a question arises; What relation do they bear in each other? When we assume Weber-Fechner's principle can be applied to this problem, we know from the described statement that the level of impaired patency for the perception of obstruction is constant, independent of the degree of obstruction.

4. Influence of Nasal Turbinates upon the Pressure in the Nasal Cavity.

The increased attention which has been paid to the resistance to the air flow in the nose gives interest to the effect of the nasal turbinates upon the

intranasal air pressure. For such determination we constructed suitable apparatus, modified after Sternstein. During the minutes the experiment lasts and the corresponding pressures are recorded in models introduced, obstracles in any description may interfere with the function of the turbinates. We measured the pronounced changes in pressure on nine types of the models. We can deduce from experiments in models of various types that obstracles of any description in lower section in the proper meatus reduce the patency of the nose more than that in the upper section, and obstructing the inferior meatus can hardly influence the perviousness of the nose, compared with other two obstracles.

We concluded that a hypertrophy of the inferior turbinate have more effect to increase the intranasal resistance than other turbinates and in practise it is most rational to improve the patency by widening the lower section in the proper meatus, namely, by cutting off the lateral wall of the inferior turbinate. Based upon these fundamental experiments we proceeded to investigate human subjects with normal at pathological nose. When the data are plotted on the ordinates and the squares of the air flow in liter on the abscissae, we obtain curves showing the intranasal resistance.

In order to show the results in a definite manner we assume the normal value is equal to 1 and the average value of pressure difference is 2.013 among persons having various nasal diseases and yet there are slight differences between the normal and the latent nasal insufficiency. Among healthy females of 16 to 19 years of age the nasal perviousness has a tendency to reduce. In cases of atrophic rhinitis we obtain results with the ratio of pressure difference less than 1.

From these results it may be theoretically estimated as the normal structure of the nose that the upper section of the proper meatus is narrower and the lower one wider or both of them have the same width. Thus we know these diameters are actually smaller than we supposed and if we assume upper section in the proper meatus is 0.2 mm. wide and the inferior meatus 0.5 mm., the necessary horizontal diameter of the lower section of the proper meatus can be calculated as 1.87 mm. in order to maintain enough patency.

5. Influence of the Nasal Septum Upon the Pressure in the Nasal Cavity.

The existence of a septum in the nose has a speculative interest and it suggests that there is some advantage to the nasal function. In above mentioned researches we paid no attention to deviations of the nasal septum. But

with regard to the form of the nasal septum the need of deeper knowledge must be called for. Concerning this problem we worked on models. We diminished the distance between the septum and the lateral wall of the nose by means of celluloid plates applied upon the septum. In these models we measured the resistance by means of water manometer and investigated whether there is any relation between intranasal resistance and the width of air passage. From the result we could emphasize that narrowing the distance of air passage and increase of air flow resulted in a considerable increase of resistance but these values depended upon the location of the deviation on the septum.

The area of the septum may be divided into four parts; anterior superior, anterior inferior, posterior superior, and posterior inferior. We applied a celluloid plate of various thickness on each of these parts and measured the patency in the nose by the same arrangement. From these measurements we could deduce that the disturbance due to the septal deviation has a definite relation with the location, namely it is most disturbed by the deviation in the anterior inferior part, secondly in the superior posterior, thirdly in the inferior posterior, and fourthly in the superior anterior part.

We proceeded with similar measurements and we now know the deviation of the septum at a part opposite the inferior turbinate affects the patency more than that which exists against the middle turbinate, if the thickness is the same in both cases.

When we compared the mechanical obstruction caused by the deviation at the level of the middle turbinate with one caused by the deviation of the same degree at the level of the inferior meatus, we could verify the latter plays a more powerful role in a mechanical disturbance to respiration. It should be emphasized that due to the geometrical relation between septum and turbinates various air passage may be designed. We made some models of nose, in which the distance between the inferior turbinate and septum was always kept at 0.5cm, but the course of air pathway was varied, and studied the influence of the direction of air course upon the patency. We could point out with confidence that the nasal respiration is more disturbed by the swelling of the turbinates than the deviation in the septum, if the width between middle and lateral wall is kept equal in both cases.

6. Influence of Oral Respiration Upon the Pressure in the Nasal Cavity.

In the light form of nasal obstruction the individual may probably continue without any detriment to breathe through the nose. When the obstruction

reaches a point where the nasal respiration becomes inconvenient, he changes to the oral respiration and this compensation makes the person obtain the feeling of obstructed nasal respiration.

A manometer was connected with the nasal cavity by means of glass tubings and another glass tubing connected with the mouth closed. We could compare the intranasal pressure with the intraoral pressure by these manometers and calculate indirectly the respiratory volume from the results obtained by these measurements.

The average value of the ratio of N to M, where N is the pressure in the nasal cavity and M is the pressure in the pharynx, is 2.765 in cases of normal noses. From this value we can conclude that the superiority of the nasal respiration is due to the fact that the nasal respiration has only slight resistance compared with the oral respiration. We studied by the same device the ratio of N to M in models made from the cast of pathological noses. The average value of the ratio of N to M is reduced in these cases and the reduction of the ratio means the increase of intranasal resistance. It should be emphasized that the small resistance in the nasal cavity is by no means least important.

7. Influence of the Temperature Upon the Pressure in the Nasal Cavity.

We have studied various factors influencing the patency of the nose which originated in the nasal cavity. On the other hand, there are many factors outside of the nasal cavity which have strong influences on the nasal patency. This latter point certainly includes important problems. Among these factors the environmental temperature has a considerable intimate relation to the nasal disturbance. We therefore venture to study this subject, to what degree does individual with normal nasal respiration react on the temperature. These persons inspired air volume of 8 liters per minute through a glass tube connected with an olive and we observed the intranasal pressure and the temperature difference between the inspired air and the environment. We measured the temperature difference which is sufficient to maintain the normal intranasal resistance for 15 minutes. We repeated this examination through a whole year and we defined favorable temperature for the nasal respiration which is well endured by a nose that functions satisfactorily without increasing nasal resistance.

In summer season when the temperature is about 29°C, the intranasal resistance is increased and the patency is considerably reduced, if the temperature of the inspired air is 1°C below than the outside temperature. In

early autumn, that is, with the daily average temperature of 15°C to 23°C, the patency is reduced, when the temperature of the inspired air is 4°C below than the outside temperature. In winter temperature, the patency is disturbed by the difference of 6°C.

We named this temperature zone as the favorable temperature zone for the nasal mucosa and the fact is ascribed to the accommodation of the nasal mucosa that the lower the atmospheric temperature, the broader is the favorable temperature zone. We get the results that the patency of the nasal cavity is influenced by the humidity not more than we supposed.

8. Influence of Medicines Upon the Pressure in the Nasal Cavity.

Beside these external factors influencing the nasal patency, we examined the effects of medicines on the nasal resistance. In rabbits respiratory air flow is 1 liter per minute and its temperature is 4°C to 17°C to keep the nasal mucosa normal.

In these conditions we examined influence of some kinds of medicines upon the nasal patency. In general we may conclude that adrenaline, pilocarpine, antihistamine and pituitrin allow the passage through the nose of the amount necessary for the satisfactory ventilation. Atropine, alcohol and histamine have a contrary effect.

Many authors studied correlation between the nasal mucosa and the nervous system. When the sympathetic is stimulated by induction shock the patency of the nose is increased and bilateral resection of the superior ganglia of the sympathetic nerve reduces it. The stimulation of the vagus nerve by the induction shock reduces the nasal patency momentarily which then gradually increases.

Concerning this problem it is of clinical interest to study the behavior of the nasal mucosa in response to the application of an ice-bag upon the back of the nose. Judging by our animal experiments, there seems to be a tendency to reduce the patency in an average 10 minutes after the application, due to a reaction of the blood vessel system, whereas intranasal resistance gradually becomes reduced while this reaction lasts. We found practically the same tendency in the human nose.

The ice-bag was applied on the back of the nose among various patients and passing the air flow of 12 liters per minute, we measured the intranasal pressure by a modified Sternstein's method. In normal cases the intranasal pressure increases in a short time which is probably due to the temporary

hyperemia in nasal mucosa. The pressure becomes reduced gradually till 14 hours after the application. This results agree exactly with those of animal experiments.

9. Measurement of Capacity of the Nasal Cavity.

The nasal perviousness can be represented by the volume of the nasal cavity. We could registered volume curves of the nasal cavity in man and we observed the volume change after application of various medicines. Adrenaline and pilocarpine increase the volume of the nasal cavity and atropine, on the other hand, exertra contrary effect.

5. Heating

1) Air Temperature and Surface Temperature of Mucosa in the Nose.

Air warming in the nasal cavity is of great importance and so many investigators made experiments using various methodes. It is difficult, however, to measure the temperature of the air passing through the nose during the short duration of the respiration phases.

We improved measuring device and measured the temperature of the surface of the nasal mucosa and of the inspired air at various plaus in the nasal cavity.

In the normal nose surface temperature of the mucosa is almost constant, being independent of the atmospheric temperature but the temperature of inspired air is influenced by atmospheric temperature. It finally acquires a constant value before it reaches the choana.

In acute inflammatory processes in the nasal mucosa the surface temperature is higher than normal but in chronic processes there is no difference from the normal.

When cocaine and adrenaline are applied on the surface of mucosa surface temperature decreases by 0.5°C to 2.5°C at the affected region but it shows a slight rise in the vicinity.

2) Experiments of Heating Mechanism of the Nasal Cavity.

We measured the temperature difference between choana and atmosphere in laryngectomied patients. From these data the temperature difference can be expressed as a function of air flow passing through the nose.

$$t - t_0 = K \left(T - \frac{t + t_0}{2} \right) Q^n$$

In other words the rate of temperature increase is inversely proportional to the inspired air volume and proportional to the difference between body temperature and atmospheric temperature and K is a function of the inspired air volume. By this formula the warming effect of the nasal cavity can be calculated when inspired air volume is known.

The formula theoretically introduced by Bloch is too simple to explain the actual phenomenon in the nose. This formula can be applied to the actual heating phenomenon in the nasal cavity.

6. Humidification

Concerning this problem there are still many details not yet worked out with exactness. We seek in a measure to supply this lack. But measurements of the humidity in small nasal cavity is difficult with an electric resistance hygrometer, since it varies from moment to moment. We improved a measuring device which is a modification of the dew point method.

The absolute humidity of the inspired air shows an increase of about 8 to 15 grams in square cm. as compared with that of atmosphere. From this result we can assume that the humidifying effect of the nose has a certain limitation. According to this result we can say that the nasal cavity gives 4 to 7.5 mg. of water to a draught of the inspired air.

Changes of temperature and humidity of atmosphere influence the humidity of the nose. In order to examine this point we measured the increase rate of the nasal humidity in various condition of atmospheric humidity.

From the data thus obtained we can construct the following equation,

$$y = k \cdot x^n$$

Where y, in the increase rate of the nasal humidity,

x, absolute humidity of the atmosphere, and

k, and n are constants.

From our experimental data and this equation we obtain the following equation;

$$y = 10 \cdot x^{-1.11}$$

Using this formula, we can calculate the relative humidity, if we can measure the temperature at choana. Our result did not indicate proportionality of the increase rate of the nasal humidity to atmospheric temperature.

The relative humidity is more significant from the physiological point of

view rather than the amount of water vapor in choana. We measured the relative humidity in the choana in various atmospheric conditions through four seasons. We can deduce from these experiments that the relative humidity increases about 40% while the inspired air travels through the nasal cavity regardless of the atmospheric temperature and humidity.

Further we discussed the mechanism of humidification in the nasal cavity.

7. Cleansing Effect

The dust removing effect is ascribed to the trapping of dust particles contained in the inspired air onto the nasal wall. This function is contributed to by each of four sets of factors namely, Brownian movement, sedimentation, inertia and edge effect.

In the nasal cavity these factors do not act separately but simultaneously. Strictly speaking, these four factors do not share equal contribution among them all over the nasal wall. This particularity gives very important and essential knowledge for understanding the cleansing.

We measured the total amount of the filtered dust in the nose by dust counter and observed the distribution and magnitude of the adhered dust on various parts of the nasal wall by microscope. In the normal condition the percentage of the filtration is 38.5% to 52% in the average. And we examine dust particles of relatively large size adhered on the lower part of the nose, the distribution of the adhered dust does not show uniformity. This seems to be due to the distribution of the inspiratory pressure in the nose and location of pathways of the air. If the nasal turbinates are removed to produce eddy curls in the nose, the filtration effect is definitely reduced to less than the half of the original value.

If the air flow is increased, the percentage of the filtration of the nose is gradually increased and reaches 55.7% to 63.7% at 12 liters per minute of air flow. On the other hand if the air flow is reduced, it is also reduced. At the velocity of 6.5 liters per minute only 31.2% to 48.9% was filtered off.

There is a close relationship between the cleansing function and the character of the surface of the nasal wall. Coating with viscous substances on the wall, such as glycerin solution, increases the effect. We coated namely the nasal wall with glycerin and observed the magnitude and distribution of dust adhered upon it. In this case we could find dust particles of small size on almost every part of the wall was contrary to the former case.

In the human nose it is naturally recognized that the vibrissae checks the

inroad of the dust. To ascertain this problem the vibrissae were attached at the entrance of the nose and we measured the cleansing effect, and compared the result with that without vibrissae. The percentage of the filtration is 82% to 89% in the latter case and dust particles of relatively large size was not observed in the nasal cavity.

From the result of this series of experiments in human nose we can conclude that the normal cleansing is about 40% to 50% and is influenced by surface character of the nasal mucosa and vibrissae. Any pathological conditions in which eddies and abnormal velocity of the air flow are produced in the nose reduces it.

8. Ciliary Action

Ciliary action plays the most important role in the nasal defensive function. As the material for the study of the ciliary action we used mucous membrane from the nose of man, rabbit and frog. We placed fragments of the nasal mucosa from the nose on the stage of the microscope and examined the ciliary motion with stroboscopic apparatus.

The effective stroke, the forward movement of the cilia is much faster and more vigorous than the recovery stroke, as is well known, and they are in the same plane. This type of motion described by an individual cilium is repeated by the neighboring cilia with a phase shift, so that the characteristic regular propagation of the wave occurs with a picture resembling wheat field blown by the wind. This well established picture is most clearly demonstrated by the author's device of observation. Detailed measurement was also possible.

The frequency of the ciliary stroke in man is from 8 to 12 per second. The cleansing in the nose can be ascribed to the movement of the mucous blanket rather than ciliary motion itself. We deposited minute particles of cosmetic powder or carmine powder upon the surface of the nasal mucosa and measured the speed and pathway of the mucus transport. The speed of mucous blanket in the anterior third is slower which is accounted for by the fact that the mucosa is not ciliated and in the posterior two third of the nose it is more rapid, where it may reach 10mm. per minute. In the human nose the direction of the mucous flow is backward and the streaming is not always in the straight line to the pharynx.

Our determination of temperature effects were made on freshly removed human mucosa and checked against similar one on living rabbits. The most powerful damage to the ciliary function is caused by drying. It entirely

depends upon a coating of moisture. The drying needs to continue for about 6 minutes to destroy the ciliary activity. Then a fresh supply of mucous fluid does not recover the cilia.

The speed and effectiveness of ciliary action can be controlled by temperature and the reaction are reversible within limits. The effectiveness and frequency of the beats was greatest between 18°C and 33°C in the nasal mucosa of rabbits and humans. In the mucosa of frogs 13°C was the most favorable temperature for the ciliary action. When the temperature was elevated or reduced, there occurred a diminution of activity which becomes more and more striking with reduction or elevation of the temperature until the ciliary motion finally ceased.

The action of ions on the ciliary movement is interesting the latter depending upon the hydrogen ion concentration. The effectiveness of ciliary activity is greatest at pH 7.8. A little alkaline or especially a little acid reaction nullifies the effect. The experimental figure of pH 7.8 which causes most vigorous motion of cilia corresponds closely to pH found in normal human secretion.

The concentration of salt solution in which the specimen of mucosa was kept can affect the frequency of beat. Cilia of rabbit remain active for a long time in a from 0.6% to 0.9% solution of sodium chloride at room temperature. In a 0.4% solution of NaCl, ciliary activity entirely ceases.

9. Absorptive and Excretory Function of the Nasal Mucosa

We examined the absorptive and excretory function of the nasal mucosa by means of injections of sulfamide, dyes antibiotics and insoluble substances.

a) Absorption and Excretion of Sulfamide.

We examined the absorption activity of the nasal mucosa of man and rabbit on the nasal application of sulfamide, measuring the quantity in jugular vein by photometric analysis. The excretion activity was determined by measuring the concentration of sulfamide in the nasal mucus after intravenous or intramuscular injections.

When sulfamide is injected intravenously, some amount can be proved to appear in the nasal secretion 5 minutes after injection and it reaches the maximum in 15 minutes and the excretion continues for 3 hours, whereas the concentration in the blood naturally reaches the maximum just after the injection and diminishes rapidly.

The total amount of sulfamide excreted out of the nasal mucosa depends on the process of application. The concentration of the sulfamide in the blood is higher by 20% in the case of the intrarterial injection as compared with the intravenous injection but its concentration in the nasal mucus does not differ so much between both procedures. In the case of intramuscular injection the sulfamide concentration in the nasal mucus is much less and it takes about 60 minutes to reach the maximum.

The absorption of sulfamide solution from the nasal mucosa can be examined by measuring its concentration in the blood, which reaches the maximum 60 minutes after the nasal application and then continues to diminish gradually.

b) Absorption and Excretion of Dye.

When this function is measured by the nasal application of dye (10% uranin solution), it appears in the jugular vein 2 minutes after the application and reaches the maximum in 60 minutes. We got the conclusion by statistical examination that the concentration of uranin solution in blood reaches the maximum 60 minutes to 110 minutes after the application.

In inflammatory condition the nasal mucosa possesses a higher permeability. In the presence of inflammation in the nasal mucosa the concentration in blood of absorbed substances is three times as high as in the normal case. Further we examined influences of many medicines in routine use upon the permeability of the nasal mucosa. We could conclude from these experiments that acetylcholine and pilocarpine increase permeability and adrenaline, antihistamine and atropine have the contrary effect.

We repeated the experiments using a solution of amarans, a red dye, instead of uranin solution and we obtained substantially the same results. The absorption effect of the nasal mucosa is hardly influenced by different hydrogen ion concentrations of amarans solution.

c) Absorption and Excretion of Penicillin.

We studied the excretion by the nasal mucosa by means of intravenous injection of penicillin. At various intervals after injection mucous membrane of the nasal cavity and maxillary sinus are extracted as the material for assay of penicillin. One-dimensional diffusion method was applied for the estimation of penicillin contained in mucous membrane and nasal mucus.

It is revealed by this investigation that the blood level of penicillin increases rapidly after intravenous application and reaches a maximal value after 5 minutes and becomes gradually reduced. The level of penicillin in the mu-

cous membrane reaches 0.3 units 10 minutes after the injection and reaches its maximum, 3 units per gram, 30 minutes after the injection and further follows a parallel time-course with that in the blood.

Changes of the level of penicillin in maxillary sinus mucosa is almost the same as that of nasal mucosa, except the time taken for reaching the maximum is 30 minutes.

The level of penicillin in nasal mucus is very low and is difficult to measure it accurately. On an average the maximal level is about 0.01 unit per cc.

In order to examine the absorptive function of the nasal mucosa we determined the content of penicillin in venous blood in various time interval after the application of penicillin into the nasal cavity in the rabbit. The results show that the penicillin can be detected in 10 minutes after the injection and then it gradually increases to reach the maximum of 0.5 units per cc. in 60 minutes.

c) Absorption and Excretion of Insoluble Substances.

We demonstrated absorption and excretion across the nasal mucosa by means of injections with carmine and Indian ink.

In epithelium these foreign injected particles are increased in number which are located in intracellular and intercellular spaces. Besides these isolated particles there are many emigrated macrophages. As can be seen from this histological results the foreign bodies are passively transferred by macrophages and it must be noted that the extraneous bodies can not penetrate the mucous membrane by themselves.

Excretion of foreign bodies is found in the epithelium where emigrated macrophages are numerous.

In the tunica propria of the mucous membrane foreign bodies are few in number. This histological finding indicates that the tunica propria represents a defensive role against foreign and insoluble substances.

In the stroma there are blood vessels, lymph vessels, nerves and glands. The foreign bodies are either phagocytized or left free in this zone. The injected agents are removed through lymph vessels and some of them through spaces between reticuloendothelial cells, phagocytized by macrophages.

In the ducts of mucous glands injected bodies are constantly and abundantly present. Sometimes macrophages are arranged around these mucous glands. These processes can be emphasized as a evidence of excretory function of the mucous membrane.

We examined histologically the excretion process in the nose by means of

injection with Indian ink into common carotid artery. The vascular system of the nasal mucosa forms a rich network. Just beneath the basement membrane, there is a network of small blood vessels and capillaries. Foreign injected bodies can be easily demonstrated in these networks in the specimen. They are returned into jugular vein. But in our specimen in which spaces between the endothelial cells of capillaries are dilated owing to the shock caused by injection with foreign bodies, injected particles can be demonstrated to have entered extravascular tissue.

The emigrated substances arrive to epithelium by avenue of lymph vessels and pass between epithelial cells, phagocytized by macrophages.

This histological finding connotes an efficiency of the vascularity in the heating and humidifying of the inspired air. The extensive network of lymph vessel offers efficient means of absorption and excretion of the nasal mucosa.

c) Defensive Function

We discussed the defensive reaction of the nasal mucosa against bacteria by means of histological examination.

In the mucosa of inferior turbinate there are numerous bacteria in the epithelium but less in basement membrane. In the neighborhood of mucous glands these elements are increased in number but the perivascular tissue contains always far less.

From the findings that in the basement membrane the macrophages are greatly increased in number when initiated by injected foreign bodies and less bacteria situated compared with other layers, we can conclude that the basement membrane plays a characteristic defense. The presence of bacteria in the vicinity of mucous glands means a defensive pattern played by the reticuloendothelial cells and macrophages.

In the nasal secretion there are numerous squamous epithelial cells and ciliated columnar epithelium cells with polymorphnuclear neutrophiles and lymphocytes. Numerous isolated bacteria are located among them but one to more than ten bacteria can be demonstrated in the cytoplasm of squamous epithelium cells. On the other hand we did not encounter such situation in ciliated or columnar cells.

From these histological examination ciliated and squamous epithelium are shown to offer excellent resistance to bacterial invasion.

10. Surface Potential

The electrical phenomenon is one of the greatest factors influencing the

above mentioned functions of the nasal mucosa. We measured the surface potential between air and surface of the nasal mucosa. The average potential obtained from the nasal mucosa of rabbit is 0.263v. But it reduces to 0.274v. after complete removal of nasal mucus. The potential difference is assumed to be due to the surface potential between air and nasal mucus. Coating the surface of nasal mucosa with medicines results in changes of the surface potential. It is increased by Bosmin, protalgol and cocaine and decreased by percamine, the changes being proportional to the concentration of the applied solution. The greater part of effects of these medicines can be accounted for by the surface potential. We believe that absorption and diffusion of these medicines to the nasal mucosa might be solved from this aspect.

11. Resonance of the Nasal Cavity

The nasal cavity represents a resonator together with pharynx and mouth. When the shape of the nasal cavity is altered the acoustical elements are altered which in turn alters harmonics composition of the output sound. These changes together with a change in the fundamental frequency of the vocal cord make it possible to produce an infinite number of different sounds. The voice mechanism then consists of a number of acoustical elements which can easily vary in pathological noses. In this respect it is certainly interesting to measure the frequency characteristics of the nasal cavity.

When the mouth is opened, the frequency characteristics of the normal nasal cavity shows slight fall between 50 c.p.s. and 130 c.p.s. When the mouth is closed, frequency characteristics show a remarkable rise between 1500 c.p.s. and 2300 c.p.s. We measured the frequency characteristics of the pathological condition of the nose by the same procedure in various patients. We measured the frequency characteristics of the upper respiratory cavities in cases of obstruction of nostrils. In general there is a considerable fall between 900 c.p.s. and 1300 c.p.s. In cases of choanal obstruction we can prove a rise between 900 c.p.s. and 1300 c.p.s. and a fall between 2400 c.p.s. and 5000 c.p.s.

Saw teeth wave contains a fundamental and a number of higher harmonics. If these sound waves pass through the nose, the wave form should be controlled by its frequency characteristics. If we apply the Fourier's expansion to these waves, we can indirectly measure the frequency characteristics. By this procedure we obtained the same results as mentioned above.

From these experimental results we can conclude that the nasal cavity exerts a definite influence upon the sound produced by the vocal cord. The

nasal cavity has complicated acoustical elements but we can conclude that the nasal cavity has a resonator effect for the high tones. And this frequency characteristics is affected by the pathological conditions of the nose. We may obtain exact knowledge about the mechanism of rhinolalia aperta and clausa, if we proceed farther with these measurements.

The above mentioned summary is an abstract of our experimental results. The aim of these researches was to acquire exact knowledge concerning the physiology of the nose. The task which the author undertook was so extensive that much is still left before attaining the aim. The author wishes to continue this research farther and in later date to deal with the questions here left unsolved.

THE DISEASES OF THE EUSTACHIAN TUBE, WITH SPECIAL EMPHASIS ON THE ETIOLOGY AND TREATMENT

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In spite of many efforts on the part of previous workers, we do not yet possess an effective and reliable treatment of the tubal disease. This might be due to difficulty in understanding the essential nature of this disease and in interpreting true etiology of it.

For several years the author has been interested in this disease and engaged himself in the study of its etiology. Beginning with anatomical and physiological observations, the author studied various aspects of this problem, and came to believe to have approached a certain, though small, extent to an elucidation of this disease in general.

The author's ultimate objective, however, which was to bring about innovation of the therapy of this disease, was not yet satisfactorily attained.

The author reported details of his studies on the following items, special emphasis being laid on his new treatments-namely spray of medicaments and introduction of suppository in the tube-and their results.

As a final word the author emphasized the necessity of a Better Hearing Clinic, such as has been attached to our clinic since 1949, regarding the pro-