THE HISTORY OF RHINOMETRY IN NORTH AMERICA

Henry L. Williams, M.D. Minneapolis, U.S.A.

The history of rhinometry in North America is at once an illustration of the ethics, character, and high intellectual attainments of the pioneers of American Rhinology and an outstanding instance of the paralysis of imaginative thinking caused by the constricting claw of traditions dead talon on their rhinologic heirs.

Many early rhinologists appear to have wondered about the purpose of the nose in relation to respiration and to the normal ability of the organism to do work. Teleologic thinking did not then seem to meet with the opprobium that now appears to be the fashionable attitude toward it.

It was suggested that the fundamental purpose of the nose is to act as a valve to control the inspiratory air flow and so match oxygen supply to the metabolic requirements of the organism. As a result "rhinostenosis" was considered by many rhinologists to be the most serious and important of the nasal disorders. It is clear that the almost complete disregard in which rhinology is held among otolaryngologists at the present time does not descend from a primary failure of the otologic pioneers to develop the concept of the "telos" or final purpose of the nose as an organ but arose from their lack of knowledge of the aerodynamic laws bearing on the driving pressure — resistance — conductance relationship in the nasal chambers.

This becomes more evident if one considers the inception of modern rhinology to be the introduction of the parabolic head mirror by Cermak and the discovery of the topical anaesthetic effect of cocaine by Carl Köller. At this time various techniques were elaborated for the correction of this assumed blockage of function. There was a good deal of indirect evidence available which made it seem to the rhinologic pioneers (and for that matter, to their rhinologic heirs) reasonable to suppose that nasal respiration is physiologically superior to mouth breathing. Therefore, nasal respiratory obstruction which presumes an increased resistance to the flow of air through the nasal chambers was considered to have a deletoreous effect on the general health of the individual which ought to be corrected.

The diagnosis of nasal respiratory obstruction or stenosis was made at first by means of anterior rhinoscopy sometimes complemented by posterior rhinoscopy and the methods for its correction consisted of varied techniques for enlarging the nasal lumen. It began to be noticed, however, that the preoperative opinion as to the presence or absence of nasal stenosis formed

---

Chief, Otology, Rhinology, and Laryngology Service, U. S. Veterans Administration Hospital, Minneapolis.

from rhinoscopy did not always coincide with the patients complaints and further that the expected symptomatic improvement to be obtained from a given lumen enlarging technique did not always occur.

At first attempts were made to make a judgment between the relative conductance of one side of the nose as compared to the other by means of devices resembling Zwaardemaker's (86) cold mirror. These did allow a judgment as to the relative nasal expiratory flow rate over a second or two, under the reasonable assumption that the expired air is saturated with moisture. It was also necessary to assume that the path of inspired and expired air is the same, a hypothesis that was not supported by the investigations of Paulsen (57) and a good many others.

Franke (29) by the use of oval tubes eight centimeters in length with a hydraulic cross section of about 50 mm^2 having small lateral openings in the tubes for measuring pressure and by the use of a bellows of given volume, attempted to relate nasal resistance, which is, of course, the inverse of conductance, to the time required for the passage of the given volume of air, while the subject held his breath.

This technic may have the virtue of locating the site of increased resistance to air flow in one or the other nasal chamber, by a variety of maneuvers, (which were later described by Craig, Dvorak and McIlreath (16) and by Semenov) (74 A), with a moderate degree of accuracy. The great disadvantage of this technique is that it puts the alae nasi and the valvular structure at the limen nasi out of action, thus excluding an important part of that resistance to air flow which the method was designed to measure.

Kayser (37) appears to have been the first to realize the role of aerodynamics in the measurement of pressure difference — resistance — conductance relationship in the nasal chambers. He attempted to measure the actual pressure difference (the driving pressure) between the circumambient air at the airway opening and that in the nasopharynx. For this latter measurement he placed an olive in the nostril of the side of the nose not being measured for resistance, which he then connected to a manometer. The nasal chamber to whose vestibule the olive is attached thus serves as a transducer of pressure from the nasopharynx, while the flow through the opposite nasal chamber is being measured by a flow meter.

These two techniques, or modifications of them, which are termed respectively "anterior rhinometry" and "posterior rhinometry" have been the only ones used, until recently, in attempts to determine the functional "normality" of that part of the upper respiratory tract constituted by the nasal chambers and vestibules.

The search for "an absolute quantitative measurement" of one of the variables while holding the others constant, has been hindered by individual habits of breathing as well as by difficulty in obtaining valid pressure measurements in the pharynx without obtunding a portion of the normal nasal resistance. It is actually not clear why there should have been so much insistence on a "normal range" for a resistance that could be applied to one patient after another by these early rhinometrists. It is, of course, possible that they were not actually interested in securing information as to the cybernetics of respiration but rather were in search of "scientific" surgical indications.

Kayser applied his measurements mostly to pathologic noses for guidance as to where, when and what kind of enlargement of the nasal lumen for the relief of "nasal stenosis" was to be done.
Kayser's surgical indications and postoperative results were no better than those of previous surgeons who had not had access to his "improved" rhinometric technique.
The reasons for this failure were not obvious until after Tonndorf (76), in his remarkable paper, "Der Weg der Atemluft in der menschlichen Nase" which he wrote as his "Dissertation" for the M.D. degree, in 1939, showed that Kayser and other later investigators were not fully aware of the hydrodynamic principles reported by Osborne Reynolds (59) (which will be considered later on.) They were also unaware of the reports of Lillie (38) and his pupil Heetderks, (recently confirmed by Stoksted (71) and Connell on the nasal cycle. Although Kayser's rhinometric data could be, at best, of only relative significance in regard to conductance in the nasal chambers, he and many other rhinologists attempted to apply them as indications for surgical procedures for the relief of "nasal stenosis" and also for the estimation of the results of such surgery.
The "lumen enlarging" procedures advised for the correction of the nasal stenoses indicated by Kayser's rhinometry did not often appear to accomplish their supposed purpose. A tendency to make the nasal chambers more and more "adequate" by increasingly destructive surgical removal of tissue developed. Protests were heard against this senseless destruction of functioning intranasal tissues.
To their credit the rhinologists of Harvard were in the forefront of the North American protestors. In 1896, J. L. Goodale, using a modification of Franke's method of rhinometry and the hydrodynamic principles of Kayser, published a paper which was deservedly awarded the Boylston Medical Prize of Harvard University. The title is "An Experimental Study of the Respiratory Functions of the Nose". He made no reference to Reynold's work but stated, "If the nasal passages are equally permeable, and one nostril be connected anteriorly with the manometer, respiration through the free nostril produces manometric excursions proportionate to those obtained in the nasopharynx, that is to say + 8 mm for expiration and — 12 mm for inspiration. If the proportion be indicated by a fraction, one finds respiration of various depths still represented by multiples of 2/3."

In a paper "On the Dynamical Theory of Incompressible Viscous Fluids and the Determination of the Criterion" it is interesting to note that Reynolds (59) stated "Therefore, as long as $\frac{2}{3}$ P $\frac{b0^3}{M^2}$ $\frac{dk}{dx}$ is of constant value, there is dynamical similarity under geometrically similar circumstances."
It is a commentary on the accuracy of Goodale's experiments that he should have virtually reached the same conclusion as Reynolds without Reynolds' mathematics.

Goodale concluded, "Inasmuch as the manner of breathing of each individual is dependent upon a natural or acquired habit peculiar to the person in question, absolute figures denoting respiratory alterations in air pressure are out of the question, even under wholly physiological conditions. In any case we must be satisfied with an approximate mean. Experiments instituted, therefore, for the purpose of comparing abnormal with normal pressure changes, must inevitably include considerable error, owing to the fallacy involved in attempting to obtain absolute results from relative and variable factors."

It is reasonable to deduce from these statements that Goodale was opposed to the use of rhinometry to form clinical conclusions that were unjustified because of the inaccuracy of the data secured by any of the rhinometric methods of which he was aware; nor did he believe that these methods could be used to draw valid conclusions as to the good or bad effect of any surgical procedure on the nose. This opinion appears to hold good to the present day.

Rhinometry appears to have suffered from the over enthusiasm of those who were seeking a "scientific" method of measuring function that would tell them what sort of surgical manipulation should be done and upon what part of the nasal chamber it should be practiced. They are unwilling to consider rhinometry as an adjunctive examination to combine with history, physical examination and, above all, previous clinical experience to arrive at a well reasoned conclusion as is encompassed under the term "clinical judgement."

Goodale stated, "Physiologically considered, the subject of nasal respiration resolves itself naturally into the following divisions:

I. The action of the nasal mucous membrane upon respired air with regard to heat and moisture;

II. The normal alterations in intranasal air pressure during the respiratory act;

III. Chemical changes effected in the air current by the nasal mucous membrane.

In regard to the first category, humidification, Goodale's experiments were so sound that his report is superior to most later observations on this facet of nasal physiology. He found for instance that the nose contributed only about two thirds of the moisture necessary to saturate dry, cold, inspired air. This can be contrasted with the statement by some authors that saturation of the inspired air for proper gas exchange in the pulmonary alveoli is one of the principal physiologic nasal functions.

It was not until Negus (48 to 53) pointed out that the anthropoid nose has regressed functionally from that of fur bearing mammals that it was again realized that "air conditioning" is a subsidiary and comparatively unimportant nasal function.

As a result of Goodale's paper conservatism in nasal surgery received a trememdous impetus.

In 1914, Holmes (35) was able to state; "When for any reason the middle turbinate and lower wall of the ethmoid have to be sacrificed, there results a deformity which practically produces all of the ill effects of mouth breathing. The inspired air is not sufficiently warmed or moistened and there almost always follows a chronic dry pharyngitis and a chronic laryngitis. Frequently, the trachea and bronchi suffer in like manner as the upper respiratory organs. These patients almost always suffer from orbital as well as nasal disturbances whenever they are subjected to the influence of cold or dry air, or to air contaminated with irritating dust or gases."

It is unfortunate that the teaching of the physiologically minded rhinologic pioneers was not taken more to heart. In a short time it was to be recommended that the first step in ethmoidectomy, as a matter of convenience, should be the removal of the middle turbinate.

Goodale's paper resulted in the virtual abandonment of any interest in rhinometry in North America for a long time. It is not likely that this was Goodale's intention. If one is to judge from his paper his intellectual attainments were such as not to allow him to adopt this anti-intellectual position. Opposition to rhinometry was attributed to him however, so that, whenever a rhinologist evinced an interest in the revival of rhinometry, the general flock of rhinologists rallied to the attack, unjustifiably flourishing the eagle of the Massachusetts Eye and Ear Infirmary, and bleating the rallying cry of Goodale! Goodale!

This was probably due to the fact that some rhinologists found that they were uncomfortable breathing the rarefied air of true nasal physiology and had retreated to the easier and more comfortable environment of old fashioned destructive or lumen enlarging surgical procedures: a rhinologic unthink that is still supported by some rhinologists. Goodale was used as a stalking horse behind which these individuals hid their nefarious activities.

Fortunately, **ex cat hedra** pronouncements appearing to emenate from the Imperial City, rhinologically speaking, of our eastern seaboard were not held in quite the awe by our European confreres that they occasioned in the United States, so that some rhinometric research continued.

However, the attitude of American Rhinology, in general, has become "don't annoy me with evidence; my mind is made up."

It is only recently that a few American rhinologists, against the scandalized clamor of the bulk, have again dared to investigate the hypothesis of the nose as a control device in the naso-pulmonary relationship.

Tonndorf's (76) paper has been mentioned as explaining one of the reasons why rhinometry has been unsuccessfull in furnishing the "absolute values" some thought are required for solution of problems related to abnormalities in nasal conductance.

He stated that he engaged in this study at the urging of his father who was disturbed by the lack of correspondence between the theoretical results which it was hoped would be obtained by surgical techniques for the correction of nasal stenosis and the measurements obtained by postoperative rhinometry.

Tonndorf found the path of inspired and expired air to be similar to that originally described by Paulsen (57) and supported by the findings of many others. It is only recently that Masing (42, 43) using a transparent nose model and the colored water technique of Reynolds (60), has been able to produce a better three dimensional schema of the paths of flow through the nasal chambers. His findings strongly support the assumption that the pathway of the inspiratory and expiratory air flow is extremely complicated and is not actually comparable to the drawings found in books of physiology such as that of Proetz (58). It seemed evident to him that the lower area of the nasal cavity must be as important as the upper in aerodynamic function.

Reynolds (59) had stated that although the theoretical calculations of Sir G. Stokes seemed to agree so closely with the experimental determinations of the flow of fluid through pipes as seemingly to prove the truth of the assumption involved, this was the result of comparing the flow of water through uniform small tubes and at slow velocities. Reynolds found these results at variance, both theoretically and practically, with water moving at higher velocity through larger tubes. He stated, as previously reported, "In 1883, I succeeded in proving - - - that when water is caused by pressure to flow through a uniform smooth pipe, the motion of the water is **direct,** i.e., parallel to the sides of the pipe, or **sinuous,** i.e., crossing and recrossing the pipe, according as $\overline{V}$, the mean velocity of the water, as measured by dividing Q, the discharge, by $\triangle$, the area of the section of the pipe, is below or above a certain value given by $K\mu/DP$, where D is the diameter of the pipe, P the density of the water, μ = the viscosity and K a numerical constant, the value of which according to my experiments, and, as I was able to show, to all the experiments by Poiseuille and Darcy, is for pipes of circular section between 1900 and 2000, or in other words, steady direct motion in round tubes is stable or unstable according as $P\frac{D\overline{V}}{\mu} > 1900$ or < 2000, the number K being thus a criterion of the possible maintenance of sinuous or eddying motion."

He pointed out that the existance of a sudden change in the law of motion of fluids between solid surfaces when $D\overline{V} = \frac{\mu}{P} K$ proved the dependence of the manner of motion of the fluid on a relation between the product of the dimensions of the pipe multiplied by the velocity of the fluid, and the product of the molecular dimensions multiplied by the molecular velocities which determine the value of μ for the fluid; also that the equations of motion for viscous fluid contained evidence of this relation.

Tonndorf found that in the tortuous passages of the human nose the "critical" Reynolds number was 1160 and that in quiet respiration the Reynolds number is close to 1000, so that even at the lowest respiratory rates the flow through the nose is of low stability with a ready production of an increasing turbulence with increasing flow rates.

He also demonstrated that quite minor changes in the contour of the turbinates and other intranasal structures would increase turbulence and resistance and decrease conductance in the nasal chambers.

It was also found that atrophic change in the lumina of the nasal chambers could be associated with increased turbulence and resistance and decreased conductance. In this he verified the fact that in patients with definite atrophy of the intranasal structures objective measurement demonstrated increased resistance and that they actually had the obstructed nose they complained of. It was not necessary to evoke the hypothesis of occluding crusts or nasal neurosis to explain the complaint.

Stoksted and Nielson in 1957 found that differences in width and resistance between the two nasal cavities react on pulmonary ventilation with alterations in frequency and depth. The relation between ventilation and alveolar ventilation may be expressed by the formula: Alveolar: vent. = Pulmonary ventilation — dead space x frequency.

From this it may be deduced that while maintaining alveolar ventilation constant, pulmonary ventilation may decrease with decreasing frequency of respiration and increase with increasing frequency. At an average frequency of 15 rpm, a respiratory volume of 500 c.c. and a dead space of 150 c.c. it is presumed that the pulmonary ventilation will be 7500 cc/min and the value of alveolar ventilation 5250 c.c./min; findings which Stoksted and Nielsen stated be within the normal range.

Each time that the respiratory frequency is increased by one from 15, the ventilation will increase 150 c.c. or 2 per cent. Consequently the measured product PxT which is proportional to the volume of transported air will increase by 2 per cent. Consequently, to obtain alveolar ventilation the product PxT must be corrected downward for "every step" of frequency above 15, and similarly upward for every step of frequency below 15. This correction may be applied by multiplying the measured product by the factor;

$$\frac{1}{1 + (F\text{-}15) \times 0.02}.$$

From the standpoint of cybemetic theory the diurnal and day to day changes in nasal resistance produced by reflexes to erectile tissues and nasal dilator muscles probably occur so that normally the alveolar ventilation may remain constant as long as the work load on the organism remains constant. Therefore, nasal resistance is only of interest or importance in normal nasal physiology as it influences the minute volume of respiration and eventually the alveolar ventilation.

From the papers of Tonndorf, Stoksted and Nielson, and others, it should be possible to deduce the fact that improved alveolar ventilation is not always achieved by surgical procedures which increase luminal cross section, but depends much more on maintaining or restoring the smooth rounded contours of the vestibuli, the limen nasi, and the turbinates, and avoiding interference with erectile tissue or dilating muscle.

This is what is meant by the term "physiologic surgery", as was recently pointed out by Anderson. (1).

Tatum (75) showed that excessive pulmonary ventilation would produce engorgement of the turbinates. Sternstein (70) found a direct physical relationship between the degree of erectile tissue swelling and the resistance produced. The effect on resistance of the alae and the valve at the limen was demonstrated by van Dishoeck (22).

Tonndorf had succeeded in demonstrating that one of the causes of the failure of rhinometrists to secure valid data was their use of incorrect hydrodynamic principles in their measurements. They had used the law of Poiseuille in a case where the law of Reynolds applied.

This probably resulted from the fact that it was stated owing to a simple arithmetic error Rohrer had made a tenfold error in the estimation of N Re (crit) and stated as a result that air flow through the nasal chambers is laminar.

The often repeated statement that if nasal respiratory obstruction is present even at rest all that the patient need do to achieve adequate alveolar ventilation is to breathe through the mouth, is a misleading part truth that, at times, almost appears to be uttered with the intention to deceive.

McKillick (40) showed that there is lowered pulmonary function in 20 to 30 per cent of apparently normal individuals. Hellman (33) stated that the physiological superiority of nasal over mouth breathing lay in the slower deeper respiration associated with the former. Davies, Haldane and Priestly (17) found that nasal blockage could cause a considerable degree of hypoxia and hypercapnia before mouth breathing will be restored to and Lücher (39A) found the same. Finally we have the reports of several pediatric groups (39) that upper airway obstruction can cause reversible for pulmonale.

The conclusion that nasal respiratory obstruction, both when noticeable even with quiet breathing and when present only at increased rates of respiration, can have morbid repercussions on the organism as a whole seems difficult to escape.

Recently attempts to relate increased nasal resistance to pulmonary respiration seem to have culminated in the "Respiron" of Cass. (11A)

A peculiarity of Cass' paper, however, is that while he mentions alveolar ventilation, and airway obstruction as a cause of dyspnoea he makes no attempt to connect dyspnoea to obstruction of the upper airway. He mentions Meads work on the partition of respiratory resistance but gives no hint of why he did so. He states that the methods of using pharyngeal and esophageal balloons simultaneously "are sound" but he suggests no purpose for such a combination.

He uses the oscillation pressure method for measurement of what he terms "total respiratory resistance" although he excludes the nose in this measurement. He uses the mask flowmeter and pressure transducer of Ferris, Mead and Opie for the measurement of what he terms nasal resistance, although the measurement is made only at the biased (controlled) flow rate of 0.5 l/s (1,800 l/hr.)

As Cass says, the method and equipment may be conveniently applied to the evaluation of the effects of medication "in conditions which cause interference with airflow in the nasopharynx."

In this regard, however, it does not seem to be a significant improvement over the technique of Goodale (1896).

It is a little disappointing to find that Cass did not even suggest that the relatively equal partition of resistance between the upper and the lowei respiratory tract might have cybernetic significance. He seems not quite able to "screw his courage to the sticking place" for the announcement of such a hypothesis. Perhaps he lacks sound, controlled, teleologic thinking or is frightened away by the spider of "arm chair science."

Brown (6A) describes use of the effect of 10 forceful inspirations on the nasal resistance to fluid flow. The evidence that hyperpnoea through the nose will usually produce dilation of the arterial supply to the turbinal erectile tissues with their consequent engorgement has been generally accepted among rhinologists for a long time.

As soon as the hydraulic cross section of the nasal chamber is narrowed more by the turbinal swelling than by the cleft at the threshold of the nasal chamber proper, van Dishoeck (20) showed that there is a rapid increase in nasal resistance. Increased resistance has been shown to be associated with a slowing and deepening of respiration; possibly as a correction to the hyperpnoea.

Instead of choosing to consider the possibility that he had uncovered an instance of normal nasal function Brown preferred to state "The data lend substance to the tentative conclusion that sniffing can be a cause of and perhaps en exacerbating factor in a pre-existing nasal stenosis."

In the small group of subjects in whom he found that sniffing decreased the nasal resistance this probably resulted from sniffing increasing the tonus of the dilatores nasi muscles with a concomitant increase in the hydraulic cross section at the nasal inlet.

This suggests that research in rhinometry without a little foundation in rhinology, even though the basic knowledge as to how the nose behaves is meager, may not prove extremely fruitful.

This is particularly exemplified in some of the papers of those who measure the pressures — resistance — flow relationship thru one nasal chamber at a time, by either anterior or posterior rhinometry, and then combine the results to obtain data on either resistance or volume flow per unit time. Until recently such papers have never considered the well supported phenomenon of the "nasal cycle", and the error this might introduce into data secured but a few minutes apart.

Guillerm (31), a pulmonary physiologist, stated that since we know that nasal resistance varies from moment to moment and that the turgescence of the nasal turbinates evolves according to a definite cycle, the periodicity of which lies between two to five hours, it is necessary to make measurements every 15 minutes over a period of two or three hours to determine the nasal cycle characteristic of a particular individual. If one then wishes to compare an immediate measurement made on an individual to another made after an interval of several hours or several days, it is necessary to be sure that the measurement is made at exactly the same phase of the cycle.

This requires that diagrams of the nasal cycles be made so that the findings can be superimposed.

Van Dishoeck (20) found that the method of Spoor (69) which gives direct values for nasal conductance by means of an electronic divider which produces the division $\frac{V^2}{P}$, has the great advantage of demonstrating the relatively constant values of nasal conductance in spite of (possibly because of) changes in pressure difference and minute volume flow.

In this method it is necessary to make the assumption that the alae nasi, have no valvular action, a position which is not supported by previous work of van Dishoeck. (20)

It would seem a reasonable deduction from the information available that a nose can be classified as functionally pathologic only when under given circumstances it does not allow the passage of sufficient air to prevent hypoxia, hypercapnia and respiratory acidosis without an expenditure of energy that is excessive for the general state of activity of the individual as compared to another who has a "normally" functioning nose. This recognizes the fact that some individuals persist in nasal breathing without additional respiratory effort even with hypoxic PA (CO_2) and acid pH levels. It would seem that if rhinometric measurements are to be of maximum value they must be correlated not only with alveolar ventilation but also with simultaneous measurement of the blood gases.

Ogura (54) is approaching this ideal method in his experimental laboratory and clinic by pulmonary resistance measurements in which both esophageal and pharyngeal balloons are used. There has always been great difficulty in obtaining valid values for pharyngeal pressure by tubes through the mouth because most people are unable to control the muscles of the tongue, palate and pharynx sufficiently to prevent their activity influencing the data obtained. Ogura has found that in the patient with significant nasal respiratory obstruction from a pathologic nose there is increased impedance in the airway even when breathing through the mouth, with an increase in functional residual capacity. He has suggested that "nasal stenosis" may cause via a pulmonary reflex, constriction of bronchial smooth muscle. The continuance of these investigations by Ogura offers hope for future clarification of nasal function and nasopulmonary relationships.

From reviewing the literature it has become apparent that no completely satisfactory rhinometric technique has been developed and that there is considerable disagreement as to what the objective or objectives of rhinometric measurement should be.

One group appears to believe that the only value of rhinometry lies in its ability to give objective answers in the assessment of nasal vasoconstrictors. They have refused the challenge of rhinologic research. A second group looks toward rhinometry as a means of deciding whether or not surgical relief of nasal stenosis is indicated and whether improved conductance has been attained, or normal conductance retained, after surgical procedures on the nasal skeleton. These seek absolute values or ranges for impedance, driving pressure and volume flow that can be applied to classes of individuals. It is apparent that they are but little closer to this goal than was Goodale just before the turn of the century, who concluded that this goal is unobtainable. The third group hopes that through the agency of rhinometry they will eventually learn a great deal more about nasal physiology and discover whether or not there is good direct evidence that the nose is one of a series of fluidic control devices through which the organism matches the impedance of the respiratory tract to the requirements of alveolar — capillary diffusion — perfusion of O_2 and CO_2. A small patch of blue is beginning to show in the overcast for the third group. It seems probable that a considerable accretion in our knowledge as to the relation of the nose to the organism as a whole shall soon be attained.

It is also clear that the advance of rhinometry and improvement of rhinometric methods have been hindered by poor communication between those interested in the physical laws of hydrodynamics and areodynamics and those interested in how and why respiratory air passes through the nasal chambers.

Osborne Reynolds (59) stated that the story as to how certain mysteries of fluid motion, which have resisted all attempts to penetrate them, are at last explained by the simplest means and the most obvious manner is closely analogous to the situation present in Poe's story "The Purloined Letter." In this story the Parisian police were completely baffled by the simple plan of destroying all **curiosity** as to the contents of a letter hanging in plain sight. Reynolds said that this is, indeed, no new story in science. Next to the motions of the heavenly bodies, the wave, the whirlwinds and the motions of the clouds had excited the philosophical curiosity of mankind from the earliest time. Both Galileo and Newton, as well as their followers, attempted to explain these by the laws of motion, and although during the last fifty years

(now 100) splendid work has been done, work which, in respect to the mental effort involved, or the scientific importance of the results, goes beyond that which resulted in the discovery of Neptune, yet the circumstances of fluid motion are so obscure and complex, that the theory has yet been interpreted only in the simplest cases. Would Galileo have discovered the laws of motion had his pendulum behaved like a box containing a heavy spinning top? This is the problem presented by fluids, in which there may be internal motion which has to be taken into account before the motion of the surface can be explained.

He also stated that the results of his investigation had both a practical and philosophical aspect, but that the results as viewed in their philosophical aspect were his primary object. In this aspect the results relate to the fundamental principles of fluid motion, and they afford for the case of pipes a definite verification of two principles, which are — that the general character of the motion of fluids in contact with solid surfaces depends on the relation of a physical constant of the fluid and the product of the linear dimensions of the space occupied by the fluid and on the velocity.

He believed that the definite association of resistance as the square of the velocity with sensibly large tubes and high velocities and of resistance as the velocity with capillary tubes and slow velocities seemed to be evidence of the way a general and important influence of some properties of fluids not recognized in the theory of hydrodynamics affect the data obtained.

Although we have heard repeatedly that from the standpoint of Physics, air may be considered a fluid of low viscosity, I think we may be pardoned for our failure to realize what a major role the internal friction of the air plays in producing increased impedance and decreased conductance in the nasal chambers.

Since turbulent fluid flow presented such difficulties to even Galileo and Newton we need not wonder that the pioneer rhinologic surgeons ignored, and even most of the present generation still ignore, the fact of its presence in planning surgical procedures to correct what they, sometimes incorrectly, termed "nasal stenosis".

One man, however, stands above the mass of his confreres in the fact of an intuitive appreciation of the importance of the contours of the nares, vestibules, limina nasi, and turbinal tissues in forming and preserving the respiratory streamlines through the nose.

It is interesting to have observed the development of his "physiologic" surgical technique.

Starting with the intra-cartilaginous incision of Orlando Roe, and replacement of the removed quadrilateral process, he advanced to the correction of the dislocated caudo-ventral edge of the quadrilateral process of the septal cartilage. He then became acquainted with the anatomic findings of Nauman in regard to the relations of periosteum to perichondrium in the region of the nasal spine; the relation of the processus lateralis frontalis to the quadrilateral process and to some unusual developments of the cartilaginous septal framework as originally demonstrated by Zuckerkandl; the relation of the premaxilla to the maxillary crest, the anterior nasal spine and the alae of the maxillary crest as demonstrated by Mosher; and combined all these anatomic facts into the maxillary — premaxillary approach to the septum and external nasal pyramid, and with correction of deformities of the external nasal pyramid, and/or baring and paring of the alar processes of the septal cartilage so as to repair of preserve the angle between the quadrilateral process and the alar processes of the septum and its valvular effect. At some time during the course of the development of his technique he realized that a rigid septum is a necessity for normal nasal function and discontinued insofar as possible removal of portions of the cartilage. He then added repair of septal perforations so as to preserve a parallel channeled nose and modified his management of the lobular cartilages so as to secure a more functionally perfect lobule. He realized that, as Tonndorf found, atrophy of intranasal structures is associated with turbulance of nasal air flow, increased resistance and at times hypoxia, so that his procedure of correcting a rhinoscopically inapparent subjective nasal stenosis by decreasing the size of the nasal lumen has, possibly, been his chief surgical triumph.

It is a remarkable record: most men seem satisfied by the addition of a single technical improvement to a surgical armamentarium.

Cottle (14), however, has never been either contented or satisfied. He has even dabbled in rhinometry. While his rhinometry does not, as yet, reach the ideal technique being striven for, it has at least alerted some rhinologists to its potential value as an adjunct examination if interpreted by a rhinologist who has gained some diagnostic acumen by carefully observing Cottle's diagnostic demonstrations.

It has been said that genius consists of an infinite capacity for taking pains. We can see that it is much more than this. It must also contain an almost computerlike ability to bypass the tedious processes of deduction and induction by which ordinary people arrive at a conclusion so that they may achieve, by "intuition", a correct solution. Genius may be unaware of this difference and become impatient with the average, who seems to persist in an almost sinful demand for concrete evidence to support those conclusions which seem so clear and so obvious to the mind of genius.

Genius must resign itself to the pedestrian pace of the average. Those who accept the conclusion of genius on the basis of its authority and emotional appeal, are but sheep of a different flock whose volatility does not presage well for the difficult journey ahead.

The hypothesis that the nose is a servomechanism to match the impedance of the respiratory tract to the demands of alveolar ventilation is admittedly of the imaginative variety.

It has, however, received considerable support, often serendipitously, from pulmonary and cardiovascular physiology, and the pediatric clinic as well as from the rhinologic research laboratory.

Sufficient evidence has accumulated to make it seem reasonable to state that the failure of rhinology to procure symptomatic relief in many patients with objective evidence or subjective complaint of "nasal stenosis" has lain in its lack of understanding of the fact, stated by Tonndorf, that we must consider the nasal air stream as a parallel stream with very little stability. Therefore, turbulence is the physical factor most greatly influencing the impedance of the nasal chambers.

This being the case, it becomes obvious that many of the surgical and simisurgical methods for improving nasal conductance have been incorrectly designed to accomplish their ostensible purpose, but often have had the opposite effect. It is suggested that subconsciously, this threat to overturn ingrained medical and surgical techniques has furnished the basis for the highly emotional content of some of the opposition to rhinometry.

Rhinometry in North America at the present time is at about the stage of development of audiology in the 1920's and electro-nystagmography ten years ago. It has a long way to go but the future seems to promise important developments in rhinometry and advances in knowledge of nasal and pulmonary physiology through the agency of rhinometry.

At the present, however, it would seem unwise to attempt to elevate speculative and working hypotheses to the status of "established fact" on the basis of rhinometric data, that owing to present inadequacy of technique; do not fully justify such an attempt.

At the present, physiologic surgery, however, seems adequately justified by observation of good results obtained and the increasing good experience of rhinologic surgeons who base their techniques, whether consciously or not, on the fact that the respired air in obeying Reynolds' "criterion" of hydrodynamics behaves like a viscous fluid.

BIBLIOGRAPHY

1. Angrist, S. W.: Fluid Control Devices. Scientific Am. 211 : 80-89 (Dec.) 1964.
2. Ballinger, W. D.: Diseases of the Nose, Throat and Ear. New York 1925.
3. Bayer, G.: Regulation der Atmung. Bethes Hdbch. d. norm. u. path. Physiol. Vol. 2 : 230, 1925.
4. Proetz. Trans. Am. Otol., Rhinol., and Laryng., Soc.. Inc. 50 : 523, 1946.
5. Boyles, The Hon. Robt.: A Defense of the Doctrine Touching the Spring and Weight of Air in: Appendix to 2nd edition, "New Experiments Physical-Mechanical-Oxford", 1662.
6. Braune, W., and Clasen, F. E.: Die Nebenhöhlen der Menschlichen Nase and ihre Bedeuting für den Mechanismus des Riechens. Ztschr. f. Anat. u. Entwick., Gesch. 2 : 1, 1877.

6A. Brown, E. A.: The Measurement of the Resistance of the Nasal Passages to the Movement of Air. I. Repeated Forceful Sniffing as a Cause of Nasal Stenosis: Review of Allergy. 21. (May-June), 1967.

7. Bruner, H. L.: On the Cephalic Veins and Sinuses of Reptiles, etc. Am. J. Anat. 7 : 1-18 (June) 1907.
8. Burnham, H. H.: An Anatomical Investigation of the Blood Vessels of the Lateral Nasal Wall. J. Laryngol. & Otol. 50 : 569-593 (Aug.) 1935.
9. Idem: Clinical Study of the Inferior Turbinate Cavernous Tissue: Its Division and their Significance. Canad. M.A.J. 44 : 477-481 (May) 1941.
10. Butler, J.: The Work of Breathing Through the Nose. Clin. Sci. 19 : 55-62 (Feb.) 1960.
11. Butler, J. and Arnott, W. M.: The Work of Pulmonary Ventilation at Different Respiratory Levels. Clin. Ace. 14 : 703, 1955.

11A. Cass. L. J.: Measurement of Total Respiratory and Nasal Airflow Resistance. J.A.M.A. 199 : 396-398 (Feb. 6) 1967.

12. Campbell, E. J. M., and Howell, B. L.: The Sensation of Breathlessness. Brit. Med. Bull. 19 : 36-40, 1963.
13. Cole, Philip: Respiratory Mucosal Vascular Response do Air Conditioning and Thermal Regulation. J. Laryng. & Otol. 68 : 613-622 (Sept.) 1954.
14. Cottle, M. H.: Concepts of Nasal Physiology as Related to Corrective Nasal Surgery. Arch. Otolar. 72 : 11, 1960.
15. Courtade, A.: Obstruction Nasale. Étude clinique et physiologique. Arch. Internat. de Laryng., Otol. and Rhinol.: 320, 598-844, 1903.

16. Craig, A. B., Jr.; Dvorak, Maria and McIlreath, F. J.: Resistance to Airflow Through the Nose. Ann. Otol. Rhinol. and Laryng. 74 : 589-603 (Sept) 1965.
17. Davis, H. V.; Haldane, J. S., and Priestley, J. Y.: The Response to Respiratory Resistance. J. Physiol. 53 : 60-69 (Sept) 1919
18. Danziger, F.: Untersuchung über die Luftbewegung in der Nase während des Atmens Mntschr. f. Ohrenheil. usw. 30 : 33, 1896.
19. Davis, D. L. and Hertzman, A.B.: The Analysis of Vascular Reactions in the Nasal Mucosa with the Photoelectric Plethysmograph. Ann. Otol. Rhinol. and Laryng. 66 : 662, 1957.
20. Dishoeck, van, H. A. E.: Mesure de la Conductivité Nasale. Rev. d'Lar., Otol., and Rhinol. intern. 2d Congrès Européen de Rhinol. (Juin-Julliet) 5 : 41-44, 1966.
21. **Idem:** Infra-Red Radiation and Nasal Obstruction. J. Hygiene, 35 : 185-198 (May) 1935.
22. **Idem:** Elektrogramm der Nasenflügel-Muskeln und Nasenwiederstandkurve. Acta-Otolar. 25 : 285-296, 1937.
23. Drettner, Börje: Vascular Reactions of the Human Nasal Mucosa on Exposure to Cold. Acta. Otolar. Supp. 116, 1966.
24. Duke, W. W.: Deformity of the Face Caused by Nasal Allergy in Childhood. J. Allergy. 1 : 466, 1930.
25. Elsner, R.; Franklin, D. L.; Vancetters, R. L. and Kenney, D. W.: Cardiovascular Defense Against Asphyxia. Science: 153 : 941-949 (Aug. 26) 1966.
26. Enghoff, H.: Halbmaske für Respirations Physiologische Untersuchungen. Skand. Arch. Physiol. 82 : 167, 1939.
27. Ferris, B. G., Jr.; Mead, J., and Opie, L. H.: Partitioning of Resipiratory Flow Resistance in Man. J. App. Physiol., 19 : 653-658 (Apr.) 1964.
28. Fluidic Systems Design Guide. Editors: Kenneth H. Johnson and Donald Fishburn, Chicago - Imp. Eastman Corp. 1966.
29. Franke, G.: Experimentelle Untersuchungen über Luftdruck, Luftbewegung und Luft-wechseln in der Nase und ihren Nebenhöhlen. Arch. of Laryngol., 1 : 230-249, 1894.
30. Goodale, J. L.: An Experimental Study of the Respiratory Function of the Nose. Boston Medical and Surgical Journal, 135 : 457-460 (Oct. 29) and 487-490 (Nov. 12) 1806.
31. Guillerm, R.; Badre, R.; Rin, R.; LeDen, R.; and Fallot, P.: La Rhinorhéographie Rev. de Lar.; Otol., et Rhinol. 5 (Supplementum 1967) : 45-60 (June) 1967.
32. Heetderks, D. F.: Observations on the Reaction of Normal Nasal Mucous Membrane Am. J. Med. Sci. 174-231, 1927.
33. Hellman, K. Untersuchungen zur normalen und pathologischen Physiologie der Nase. Ztschr. f. Laryng. unsw. 15 : 1, 1927.
34. Hess, W. R.: Die Regulierung der Atmung. Leipzig, 1931.
35. Holmes, E. M.: Clinical Classification of Ethmoiditis. J.A.M.A. : 2098 (Dec.) 1914.
36. Holmes, T. H.; Goodell, Helen; Wolf, S. and Wolff, H. A.: the Nose. Springfield, Ill. Chas C. Thomas, 1950.
37. Kayser, R.: Die exacte Messung der Luftdurchgängigkeit der Nase. Arch. F. Laryngol. 3 : 101, 1895.
37A. Kayle, Braden.
38. Lillie, D. I.: Some Practical Considerations of the Physiology of the Upper Respiratory Tract. J. Iowa Med. Doc. 13 : 403-408 (Oct.) 1923.
39. Luke, M. J.: Mehrize, A; Folger, G. M., Jr. and Rowe, R. O.: Chronic Nasopharyngeal Obstruction Causing Cor Pulmonale. Pediatrics 37 : 762-768 (May) 1966.
40. McKillick, Esther M.: Resistance to Inspiration; It's Effect on Respiration in Man. Journ. Physiol. 84 : 162-172 (May 13) 1935.
41. Manchioli, G.: Importanza della respirazione nasale nei lavoratori. Rass. di. med. indust., 13 : 36-45 (Jan.) 1942.
42. Masing, Helmut: Untersuchungen über den Strömungsverlauf im Nasenmodell. J. Arch. klin. u. exp. Ohren-Nase-,Kehlkopfheil. 189 : 371-381, 1967.
43. Idem: Patho-physiology of the Nasal Airflow, Rhinol. Internat. 5 : 63-68 (June) 1967.
44. Mendel, H.: Physiologie et pathologie de la respiration nasale. Paris-Maloin et Cie. 1897.
45. Mink, P. J.: Physiologie der obern Luftwege. Leipzig-Vogel, 1920.

46. Müller, Otto: Luftbewegung in der Nase und Wirkung des Herz. Arch. f. Hals-Nase-, u. Kehlkopfheil. 101, 1917-1918.
47. Nakano, Tomio: Influence of Nozzles on Pressure and Flow Measurement Studied by means of the Artificial Nose and the Conductivity Meter. Internal. Rhinol. 5 : 183-196 (June) 1967.
48. Negus, Victor: Observations on the Exchange of Fluid in the Nose and Respiratory Tract. Ann. Otol., Rhinol., and Laryngol. 66 : 344-363 (June) 1957.
49. **Idem:** The Air Conditioning Mechanism of the Nose, Brit. Med. J. 4963 : 367-371, 1956.
50. **Idem:** The Function of Mucus. Ann. Roy. Coll. Surg. Eng. 34 : 400-403 (June) 1964.
51. **Idem:** Collagen Disorders of the Respiratory Tract. Ann. Otol., Rhinol, and Laryngol. 66 : 699-705 (Sept) 1957.
52. **Idem:** The Action of Bronchial Muscles. Acta Otolar. 57 : 404-409 (Mar.-Apr.) 1964.
53. **Idem:** The Comparative Anatomy and Physiology of the Nose and Paranasal Sinuses. Edinburgh-Livingstone, 1958.
54. Ogura, J. H.; Togawa, K.; Dammkoehler, D.; Nelson, J. R. and Kawasaki, M.: Nasal Obstruction and the Mechanics of Breathing. Arch. Otolar. 83 : 135-150 (Feb.) 1966.
55. Ogura, J. H.; Nelson, J. R.; Dammkoehler, R.; Kawasaki, Masashi; Togawa, Kiyoshi. Experimental Observations of the Relationships Between Upper Airway Obstruction and Pulmonary Function. Ann. Otol., Rhinol., and Laryngol. 73 : 381-403 (June) 1964.
56. Macintosh, R.; Mushin, W. W. and Epstein, H. G.: Physics for the Anaesthetist. 2nd Ed. Springfield, Chas. C. Thomas, 1958.
57. Paulsen, Emil: Experimentelle Untersuchungen über die Strömung der Luft in der Nasenhöhle. S. ber. Akad. Wesnsch. Wien, Math. Natur. 85 : 352, 1882.
58. Proetz, A. W.: Air Currents in the Upper Respiratory Tract and Their Clinical Significance. Ann. Otol., Rhinol., and Laryngol. 60 : 439-467 (June) 1951.
59. Reynolds, Osborne: Reprint of "Papers on Mechanical and Physical Subjects". Vol. 2 : 51-105. Cambridge Univ. Press. 1901.
60. **Idem:** Study of Fluid Motion by Means of Colored Bands. Proc. Roy. Inst. Gt. Br., June 2, 1893.
61. Rosenthal, G.: L'insufficience respiratoire. Presse md. : 129-and 177, 1904.
62. Scheideler, J.: Die Messung der absoluten Luftdurchgängigkeit der menschlichen Nase. Arch. Ohren-Nase- u. Kehlkopfheil. 146 : 170-179 (23 June) 1939.
63. Schulthess, G. von: Temperature Measurements in the Respiratory Tract of Laryngectomized Patients. Acta Otolar. 57 : 325-331, (Mar-Apr) 1958.
64. Seebohm, P. and Hamilton, W. K.: A. Method for Measuring Nasal Resistance without Intranasal Instrumentation. J. Allergy. 29 : 56-59 (Jan.) 1958.
65. Sercer, A.: Über die Beeinflüssung der Bronchien von der Nase aus. Arch. Ohr.-, u. Kehlkopfheil., 16 : 264-275, 1952.
66. Simmons, D. H.; Linde, L. M.; Shapero, B. J.: The Effect of Blood Gases and Acid-Base Disturbances on the Pulmonary Circulation. Diseases of the Chest. 48 : 347-350 (Oct.) 1965.
67. Solomon, W. R.; Stohrer, A. W.; Considerations in the Measurement of Nasal Patency. Ann. Otol., Rhinol., and Laryng. 74 : 978-990 (Dec.) 1965.
68. Speizer, F. E. and Frank, N. R.: A Technique for Measuring Nasal and Pulmonary Flow Resistance Simultaneously. J. App. Physiol. 19 : 176-178 (Jan.) 1964.
69. Spoor, A.: A New Method for Measuring Nasal Conductivity. Intern. Rhinol. 3 : 27-35 (Jan.) 1965.
70. Sternstein, H. J.: Dynamics of Nasal Respiration. Bull. N. E. Med. Cen. 4 : 28-30 (Feb.) 1942.
71. Stoksted, P.: Étude rhinométrique du cycle nasal. Acta. Otolar. Supp. 199 : 143-181, 1953.
72. **Idem:** Border between Normal and Pathological Nasal Passage. Acta Otolar. 44 : 259-264, 1954.
73. Stoksted, P. and Nielsen, J. Z.: Rhinometric Measurements of the Nasal Passages. Ann. Otol. Rhinol. and Laryng. 66 : 187-197 (Mar.) 1957.
74. Takahashi, K.: Vorläufige Mitteilung über die Erforschung der Luftstromweges in der Nase des Menschen in vivo. Ztsch. f. Laryngol., Rhinol., unsw. (Leip) 11 : 203-208, 1922.

74A. Semenov, Herman: Personal Communication.
75. Tatum, A. L.: The Effect of Deficient and Excessive Pulmonary Ventilation on Nasal Volume. Am. J. Physiol. 65 : 229, 1923.
76. Tonndorf, Juergen: Der Weg der Atemluft in der menschlichen Nase. Arch. Ohren-, Nase- u. Kehlkopfheil., 146 : 41-63 (Mar.) 1939.
77. Tromp. S. W.: Influence of Weather and Climate on the Hypothalmalic Thermoregulation Efficiency and the Effect on Asthma, Bronchitis and Rhinitis. Internat. Rhinol. 3 : 49- (Jan.) 1965.
78. Widdicombe, J. G.: Respiratory Reflexes from the Lungs. Br. Med. Bull. 19 : 15-20 (Jan.) 1963.
79. **Idem:** Respiratory Reflexes; in Handbook of Physiol. **Sect. 3. Respiration.** Section Eds: Wallace O. Fenn and Hermann Rahn. Chap. 24 : 585-630 Washington, D. C.- Physiological Soc. of Am.-, 1966.
80. Wit, G. de, Kapteyn, F. A. and Bochove, W. M. van: Some Remarks on the Physiology of the Vestibulum and the Isthmus Nasi. Internat. Rhinol. 3 : 37-42 (Jan.) 1965.
81. Worms, G. and Bolotte, M.: L'insuffiance respiratorie nasale. Paris-Maloin, 1928.
82. Wright, J.: The Contractile Elements in the Connective Tissue. : $\frac{\text{Insert}}{11}$ The Elastic Fibers in the Nasal Mucosa in Health and Disease. N.Y. Med. J. 91 : 729, 1910.
83. Yasa, K.: Atemphysiologische Untersuchungen über die Störung der Nasenatmung. J. Orient. Med. 30 : 122, 1939.
84. Zuckerkandl, Emil: Geruchsorgan: Anatomische Hefte. 5 : 131-145, 1895.
85. Zwaardemaker, H. and Ouwenhand, C. D.: Die Geschwindigkeit des Atemstromes und das Atemvolumen des Menschen. Orderz. ged. in Physiol. Laborat. d. Utrecht Hoogesch. 5 : 250, 1905.
86. Zwaardemaker, H.: Die Luftbrücke. Vierchows Arch. Supp. 399, 1902.