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Experimental study of velocity fields in a human nasal fossa by laser anemometry

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SUMMARY

Velocity fields for various cross sections of a model of a normal human nasal fossa were determined by laser anemometry, a dynamic, quantitative and non-invasive technique. Velocity fields showed, in the laboratory, the very definite influence of the irregular architecture of the fossa on the characteristics of flow namely the streamlining action of the turbinates, the directional effect of the liminal valve and the greater velocity near the floor and the septum. They also allow a more precise evaluation of the flow mode than the Reynolds number. The aerodynamic effects of certain non-obstructive deformities were discussed.

INTRODUCTION

Laser anemometry is an non-invasive and quantitative technique used to measure very precisely air velocity at any given point within a conduit. The interest of this technique is that, by measuring air velocity at numerous points of a cross section of a model of nasal fossa, we are able to obtain a velocity field which is a quantitative and dynamic tridimensional representation of the flow of air through that section.

Laser anemometry is thus considered a tool to determine the aerodynamic effects of shapes and dimensions of the irregular nasal fossa in the same way that aeronautical engineers use wind tunnels and naval architects use test tanks to evaluate the effects of the shape of this machine as they move in their respective fluid. Static evaluation of nasal airflow had been done by measuring pressure at various points of a model of a nasal fossa by Bilgen et al. (1974) and it was felt that the dynamic evaluation of flow provided by velocity field obtained by laser anemometry would allow additional understanding of the aerodynamic effects of shapes and dimensions of the nasal fossa.

This study was presented in detail by Girardin in 1976 and 1983. A brief presentation of the experimental set up and a description and discussion of some of the

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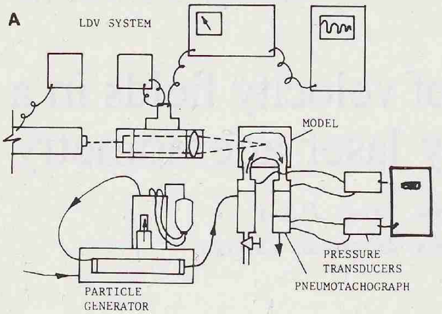

Figure 1 A.
Experimental set up.

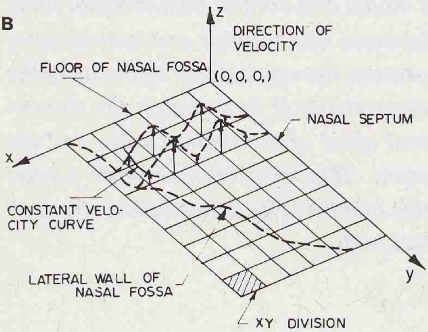

Figure 1 B.
Three dimensional coordinate system used in mapping velocity fields by computer.

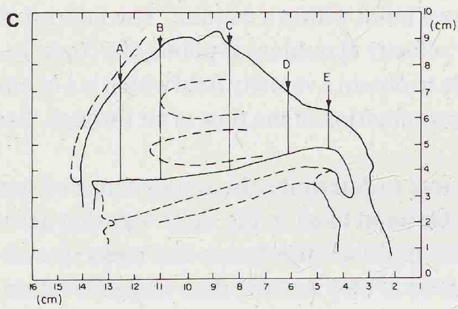

Figure 1 C.
Outline of model and measured dimensions, cross sections studied are indicated by the arrows A, B, C, D and E.

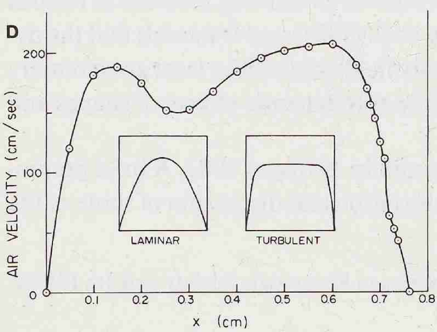

Figure 1 D.
Velocity profile in Section E, height 1.05 cm, flow 10 L/min. Typical laminar and turbulent profile are shown in inset for reference.

results will be given here to show the concept of velocity fields and an experimental method to determine them.

The Experimental Set Up and Methods

The experimental set up schematically shown in Figure 1A, consists of a laser anemometer called laser doppler velocimeter (LDV), the model of a normal nasal fossa, an air pump, a pneumotachograph and pressure transducers and a water particle generator. Studies were made at various cross sections of the fossa illustrated in Figure 1C.

For studies simulating inspiration, air containing calibrated particles of water is pumped into the vestibular connection of a bioplastic model of a human nasal fossa and the nominal flow is measured by the pneumotachograph and adjusted to 0.166 L/sec representing an average unilateral flow taking into consideration various engineering data. Air is introduced into the nasopharyngeal connector for study of simulated expiration.

The helium-neon laser beam determines velocity by measuring the speed of water particles in suspension. The laser source is mounted on a vernier grid system to allow precise and reproducable movement in relation to the depth, width and height of the fixed model.

The hypothetical cross section shown in Figure 1B illustrates the method of recording measurements. The outline of the fossa is upside down to allow tridimensional effect. The width of the fossa is ordinate OX, it is parallel to the floor of the nose. The height is an ordinate OY, it is parallel to the septum. The length of the arrow of the ordinate OZ indicates the velocity. After velocities are obtained for a certain number of points, for a given height of a cross section, the tip of the arrows are joined by an interrupted line to give a velocity profile. The constant velocity curve joins certain velocities to allow easy interpretation of the distribution of velocity of cross section in the same way that elevation lines allow easy evaluation of contour elevation of terrain. The distance between measurements varies between 1 and 5 mm; between 100 and 350 measurement points are made for each section.

To validate the measurements the flow, calculated by integration and/or planimetry of all profiles for a section, has to match the nominal flow obtained by the pneumotachography by 10%. Then these velocity profiles are introduced in a computer program to obtain the velocity field for that section and additional measurements and calculations are made as presented in the Table.

Results and Analysis

The cross sections studied were selected because of their clinical significance, their location is shown in Figure 1C. Section A is through the liminal valve area, Sections B, C and D are through the preturbinal, turbinal and post turbinal areas

Velocity fields in human nasal fossa – calculated data for sections A through E.

cross section	Y_t cm	X_t cm	A_t cm^2	V cm^3/s	Q_{nom} cm^3/s	Q_t cm^3/s	Diff %	Re
inspiration								
A	3.06	0.614	1.879	86	164	180	+ 9.8	1,320
B	4.71	0.635	2.991	66	177	198	+ 11.9	992
C	5.00	0.504	2.521	62	170	157	7.6	765
D	2.44	0.957	2.336	74	177	172	– 2.8	1,360
E	1.16	0.734	0.851	197	173	168	– 3.1	2,380
expiration								
A	3.05	0.621	1.894	83	165	157	– 4.9	1,150
B	4.97	0.533	2.651	59	165	157	– 4.9	765
D	2.21	1.013	2.239	69	165	155	– 6.1	1,290

Y_t = max height cm; X_t = max width cm; A_t = cross section cm^2/s; V = flow cm^3/s; Q_{nom} = nominal flow introduced in the model cm^3/s; Q_t = calculated flow cm^3/s; Diff = difference between nominal and calculated flow percentage; Re = Reynolds number = VDH/ν, (V = velocity, DH = hydraulic diameter, ν = viscosity of air 20°C - 0.149 cm^3/s).

respectively. Section E is through the nasopharynx and it was selected because there is a change of the direction of flow in a narrow passage. All the sections were studied for inspiration and only Sections A, B and D were studied for expiration. Velocity fields for only Section A and D are presented here.

Section A, Figure 2, through the preturbinal area, has the smallest cross section of the nasal fossa and it is irregularly shaped. Velocity in excess of 150 cm/sec can be observed in the lower portion during inspiration and a low condition of 50 cm/sec is observed in the upper half as indicated by the constant velocity curves. The area of high velocity is believed to be the result of directional action of the liminal valve.

It is very interesting to see how the velocity field in this section changes during expiration. The flow is more uniformly distributed throughout the section and the high velocity in the lower portion seen during inspiration is not visible. We believe that the change in the velocity field seen in expiration is the result of the streamlining effect of the turbinates, this cross section being located behind the turbinates during expiration.

Section D, Figure 2, is through the post turbinal area and it has a shape different from the other sections. Again the velocity field is quite different for the two directions of flow. During inspiration the flow is almost uniform with the exception of a small area of higher velocity near the septum in the lower part of the fossa. During expiration, high velocity is noted in the middle portion of the fossa reaching well in excess of 150 cm/sec. It is believed that the turbinates have a streamlining effect during inspiration. The high velocity during expiration is the

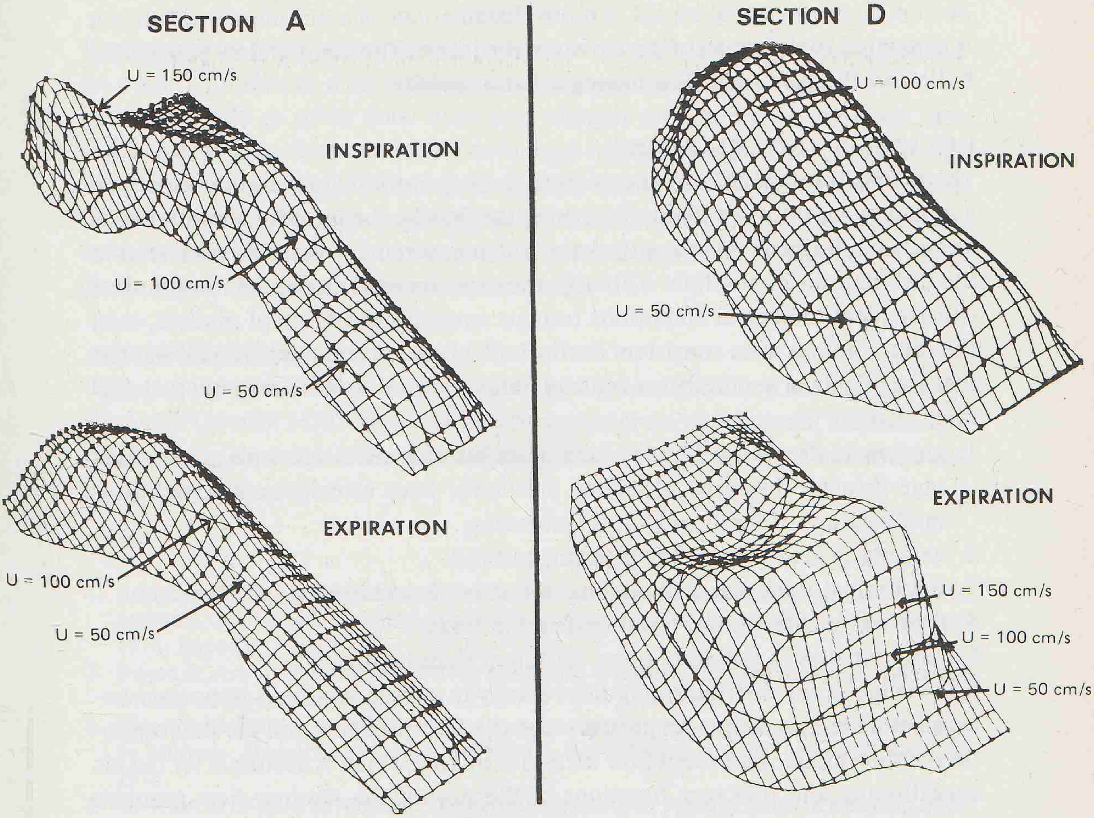

Figure 2. Velocity fields for Section A and D during inspiration and expiration.

result of a sudden change in direction of the air flow as it moves from the nasopharynx into the nasal fossa.

The Table shows the other data obtained directly by measurement with the optical anemometer or by calculation. The velocity and the Reynolds number are of particular interest. Velocity (flow in cm^3/sec) is inversely proportional to the dimension of the cross section, as the cross section decreases the velocity increases, for instance velocity is much greater in Section E, smaller cross section than in Section D, larger cross section.

The flow mode is said to be laminar when the Reynolds number is smaller than 2100 and turbulent when it is greater than 2100. If one looks only at the Reynolds numbers obtained for each section, one would say that, except for Section E, during inspiration the flow mode in the nasal fossa is laminar.

It was thus very interesting to detect strong local turbulence in the velocity profiles with the use of laser anemometry. As an example, this velocity profile in

Section E, shown in Figure 1D, is more characteristic of a turbulent flow when it is compared to the shape of the curves in the insert. The laminar flow being parabolic and the turbulent flow having a flatter profile.

DISCUSSION AND CONCLUSION

The main advantage of laser anemometry is the possibility to measure velocity in a model of nasal fossa without disturbing the flow by the introduction of a probe or hot wire. Because it is an optical method, measurement in the meati lateral to the turbinates is impossible. Although the experimental model did not simulate exactly ideal biological conditions (mucus covering, elasticity of mucosa, etc.) the shortcomings were consistent during both phases of respiration and it was felt that the effects of geometry on velocity fields were valid. We were able to determine that:

1. air flow is streamlined by the turbinates but this effect takes place after passage through the turbinal section and lower peak velocity is observed after modification of the flow by the turbinates;
2. velocity is greater near the septum;
3. the liminal valve has a directional effect on flow during inspiration;
4. flow was greater in the lower half of the fossa;
5. nasal air flow is probably more turbulent than laminar.

Knowledge of the distribution of the velocity in a cross section is important because of its relationship with pressure and the Venturi effect and the determination of flow mode. Turbulent flow increases mixing which is desirable for the air conditioning and olfactory functions of the nose while laminar flow requires lower pressure gradiant for movement hence less work. But greater velocity creates a decrease of intraluminal pressure with greater Venturi effect which could have adverse effects on certain cavities adjoining the nasal airway; greater velocity also causes greater local evaporation with resulting drying action. It was thus felt that this study substantiates the hypothesis that aerodynamic factors are important in the genesis of certain specifically located conditions such as atrophy and metaplasia of the mucosa of the anterior septum, posterior epistaxis usually behind a septal deformity, carcinoma of the nose in hardwood workers beginning in the head of the middle turbinate as stated by Hatfield (1970), pathological disturbance of the paranasal sinuses, Gray (1967), eustachian tube dysfunction in divers associated with non obstructive nasal septum deformities reported by McNicoll (1975) and even the inner ear, Goodhill (1981).

Further studies should be carried out with models simulating biological conditions as well as changes in geometry in pathological noses.

The construction of such models could be facilitated by using whole organ section as reported by Bridger and Van Nostrand of Toronto (1976).

RÉSUMÉ

L'anémomètre laser, helium-neon, permet de mesurer la vitesse d'écoulement à un point à l'intérieur d'un conduit, de façon précise et sans artefact.
Cette méthode se prête donc bien pour obtenir en laboratoire, bien sûr, des champs de vitesse dans un modèle de la fossé nasale normale. On peut ainsi voir l'influence des grandeurs et formes de la fossé nasale sur les charactéristiques de flot. Forts de ces données expérimentales, nous croyons logique de penser que certains états cliniques du nez peuvent être la résultante de perturbations aérodynamiques autres que l'obstruction nasale.

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