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A practical guide to the construction of a "cire perdue" model of the human nose

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SUMMARY

A step by step method of constructing a model of the human nose is described. The hollow model faithfully reproduces the main features of the internal structure of the nasal air passages and nasopharynx. A model constructed by this technique was found to be suitable for nasopharyngeal airflow studies.

INTRODUCTION

Despite projecting from the face as a triangular pyramid, the nose is an extremely difficult organ to examine from a physiologic viewpoint. Any manipulation of the external pyramid, such as when using a nasal speculum, immediately alters the functional anatomy of the valve area (McLean et al., 1976). As the major flow resistive segment of the entire respiratory tract is located in this region, (Bridger et al., 1970), any change in the shape or size of the vestibule and valve area will markedly alter resistance (Van Dishoeck, 1965).

The positioning of an instrument in the nasal cavity to carry out airflow and pressure measurements immediately invalidates such measurements due to the presence of the instrument. Ingenious methods have been devised to overcome such problems in the development of rhinomanometric apparatus (Cole et al., 1980). Considering these *in vivo* difficulties, I decided to construct a model of the nose in order to test a new airflow turbulence measuring instrument prior to its introduction into clinical practice.

The nasal structure, consisting of bone and cartilage, has a constant overall shape, i.e. slit-like chambers with a trapezoidal outline. However, the mucus membrane lining of the nasal cavities is continuously changing and behaves as a dynamic resistor. The lumen of the nasal airway is regulated by capacitance blood vessels, situated beneath the mucus membrane of the turbinates and septum (Malm, 1975). The normal spontaneous vascular changes account for the nasal cycle (Eccles, 1978). Even though the overall shape of the nose is constant, the flow resistive segments of the turbinated areas are constantly changing. Therefore, an exact model of a human nose is impossible to construct, because not only is one person's nose different to another, but an individual's nose changes from hour to hour. Swift et al. (1977) noted that even though models, constructed from casts of the nose made at post mortem, varied from one to another, the characteristics of airflow are very similar from model to model.

The theory of casting a complete model of a nose from a cadaver is simple. However, the reality of such an endeavour was fraught with innumerable technical difficulties. The method of construction outlined here is the end result of many months of experimentation, when the number of negative findings greatly outweighed the positive results. Only the relevant negative findings will be reported along with the method finally arrived at.

HISTORICAL BACKGROUND

Throughout the twentieth century many attempts have been made to construct a model of the human nose to obtain a better understanding of nasal airflow physiology. It was not until the pioneering work of Proetz that any attempt was made to construct a model which resembled the real nose (Proetz, 1951). He was dissatisfied with statements made on nasal physiology, based on experiments with such things as glass boxes, where no attempt was made to simulate the anatomical shape of the real nose (Proetz, 1953a). His original experiments were done using sections of a cadaver head but were found to be unsatisfactory. Later experiments were carried out on models, cast at post mortem, using liquid latex (Proetz, 1953b). It was using these models he described the air currents in the nose which are still widely quoted in text books of nasal physiology (Scott-Brown, 1979).

Swift and Proctor later used models, cast from cadavers, to demonstrate the physical principles regulating the access of air to the respiratory tract (Swift et al., 1977). Their work on the fluid dynamics of flow through the nose was done using an exact scale model of a hemisection of the nose made from clear polyester resin. There is no doubt, from the work of Swift and Proetz, that a model cast from a hemisection of a cadaver head gives consistent and reliable information, from which the patterns of airflow through the real, living nose, can be predicted. However, all this work relates to flow through one nasal passage and does not take into account the influence of each separate airstream on one another as they enter the nasopharynx.

As my interest lay in the influence of altered inspiratory airflow on the nasopharyngeal opening of the Eustachian tube, it was necessary to build a model of the complete nose, including the nasopharynx.

METHOD AND MATERIALS

To avoid confusion in terminology I shall refer to the hollow nasal passages as the negative, and a solid representation of them as the positive. The objective I set out to achieve was a negative of both nasal passages and nasopharynx in a block of transparent material. The correct term for this is CIRE PERDUE (CIRE = wax, PERDUE = lost) transparent investment casting technique (Figure 1). Having examined many cadaver specimens in the dissecting room, it became obvious that the most accurate representation of the nasal passages would be obtained from a body recently deceased. Therefore, an adult male, awaiting post mortem examination, who had died within the previous two hours was selected. The nasal cavities were examined to exclude any significant abnormalities and then flushed

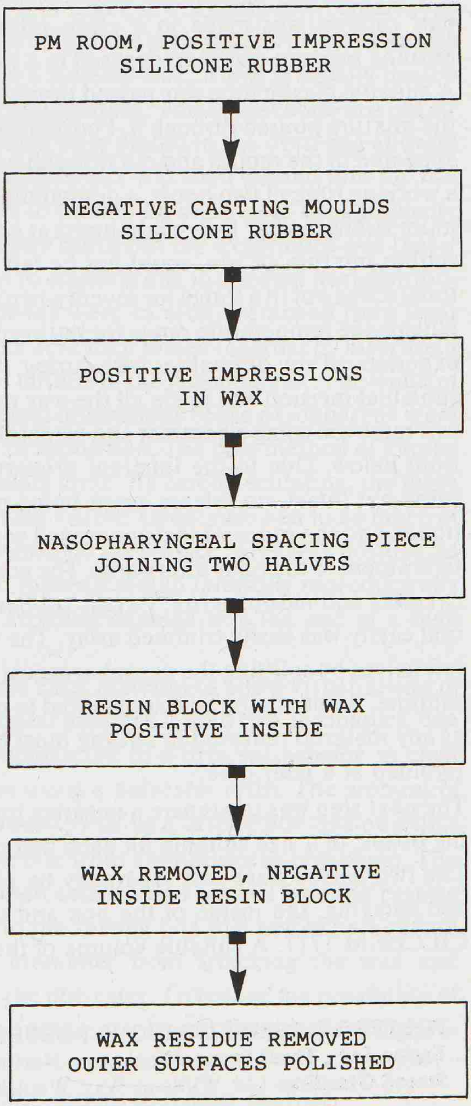

Figure 1. The principle steps in construction of the model.

clean with water. Having blocked off the oesophageal opening to prevent regurgitation of stomach contents, the subject was so positioned that the openings of the nostrils were in a horizontal plane.

The best material, to obtain an impression was found to be a two-part silicone rubber, RTV (room temperature vulcanising), POR A MOLD 5131.[1] When cured, the material has high tensile properties and tear strength with great flexibility, perfect shape reproduction, minimum shrinkage and excellent release properties. All of these features were necessary to enable withdrawal of the mould from the undercuts below the turbinates. A mixture of ten parts uncured rubber to one part catalyst was made in a clean mixing bowl and thoroughly stirred. The ensuing mixture was then degased in a vacuum chamber to remove air bubbles. A suitable plastic tube was passed through the nostrils into the nasopharynx and the mixture poured through it. Pouring continued until the low viscosity solution appeared in the mouth and out through both nostrils. The uncured mixture gives a working time of two hours, a demoulding time of twenty-four hours with maximum strength after forty-eight hours at room temperature. As the body, with the rubber mixture *in situ,* could not be left at room temperature for this lengh of time, it was put in a fridge for seventy-two hours at six degrees centrigrade. This is outside the temperature range for setting of the RTV rubber solution but I did not experienced any difficulties with curing. At the beginning of the post mortem, a sublabial incision was made all the way round the alveolar ridge, the hard palate was removed using a hammer and osteotome enabling the mould to be teased out from below. Due to the inherent properties of the silicone rubber, the mould came out intact, no release agent being necessary. The hard palate was repositioned and the mucosal incision closed with catgut. There was no noticeable disfigurement to the body afterwards. The positive mould obtained was of both nasal cavitites and nasopharynx. Excess rubber due to creepage into the sinuses and oral cavity was easily trimmed away. The mould was next divided into right and left halves by splitting the nasopharyngeal portion, with a very sharp blade, in the midline. Before doing so it is essential to measure the width of the nasopharynx, as any material removed in cutting must be made good when the two halves are rejoined at a later date.

The next step was to prepare a negative impression of the cast obtained. Moulding boxes, of a size suitable for each half of the positive casting, were obtained. The two halves were cast separately by placing each one on its medial surface and spraying, the inside of the box and the cast, with a release agent such as CILCHEM 1711. A suitable volume of the same RTV silicone rubber was cata-

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[1] POLYESTER RESINS/SILICONE RUBBER:
Trylon Ltd., Thrift Street, Woolaston, Northants NN9 7QJ, England.
Strand Glassfibre Ltd, Williams Way, Woolaston, Wellingborough, Northants, England.

lysed, thoroughly mixed and deaerated in a vacuum. It was then poured over the positive castings in their boxes and allowed to set. When fully cured the blocks of rubber were taken from their boxes and the original positive castings removed, the release agent greatly facilitating their removal. One had then reproduced a flexible negative of each nasal passage and both sides of the nasopharynx.

The next step was the preparation of a positive in wax.[1] Not all modelling waxes are suitable for the CIRE PERDUE technique, the special characteristics necessary are when the wax is being "lost" it must leave the cast cleanly without residue and it must be inert to casting material with which it will come into contact, e.g. polyester or acrylic. There should also be minimum shrinkage, with exact mould copying characteristics. Having selected a suitable wax, it was gradually heated past the melting point up to its pouring temperature. This is best done in a hot air oven. The silicone rubber negative moulds were placed in the oven and allowed to approach the temperature of the wax. The wax was then poured into the hot mould, the oven turned off and the wax in the mould allowed to cool gradually overnight. Rapid cooling may give a better finish but my experience was that it caused unacceptable shrinkage and lead to cracking due to unequal heat distribution. When fully cooled, the wax positives were carefully removed from their flexible moulds. The right and left halves were then joined together by inserting a spacing piece of wax which followed the outline of the nasopharynx. The width of the spacing piece was such that the original dimensions of the nasopharynx were reproduced when all three pieces were in apposition. The best method of joining the pieces of wax was using a heated palate knife. By careful sculpting, the three pieces were joined without any joint being visible. Great care had to be taken at this stage not to cause any damage or blemish to the surface of the wax positive, as the subsequent casting in a transparent material would faithfully reproduce any defects introduced. The best way of avoiding damage was the use of a high melting point wax.

The wax positive now had to be cast in a clear material to allow visualization of the interior of the nasal and nasopharyngeal passages. I used two techniques, one relatively cheap, the other being sub-contracted to a firm specialising in clear casting acrylic. The first technique was using a polyester resin. The amount of finishing required to the model was reduced by using a casting box treated with a release agent or making a suitably sized box from aluminium or polythene. The preactivated resin chosen was mixed with catalyst and poured into the casting box. The wax positive was suspended in the casting box just before gelling had occurred. This prevented the active monomer from attacking the wax and leaching any of the wax's pigment into the polyester. To reduce the possibility of the block subsequently cracking, due to exotherm released during the curing pro-

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[1] WAXES: Alec Tiranti Ltd., 70 High Street, Theale, Berkshire, England.

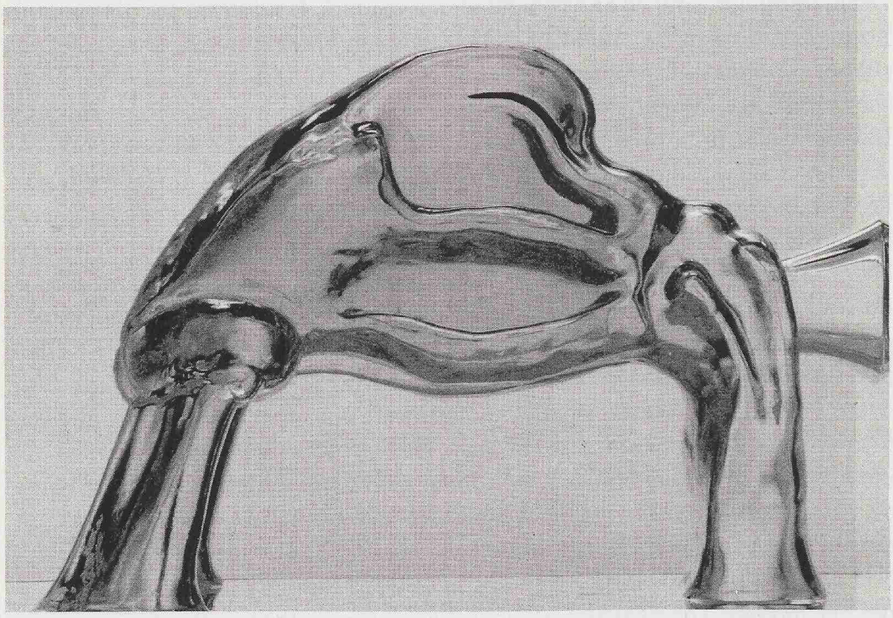

Figure 2. Photograph of the finished model.

cess, the box was placed in a circulating cold water jacket which provided cooling. When fully cured the solid block of resin with the wax positive was removed from the casting box. The layer of resin exposed to the air remained sticky and was covered over with a layer of mylenex sheeting to prevent uncured resin being transferred to the other surfaces.

When cured, a hole was drilled through the resin into the wax nasopharynx. The block was then placed in a hot air oven and the temperature gradually brought up to the melting point of the wax. The majority of the wax was removed thus and the block allowed to cool very gradually. Any wax residue within the hollow of the resin block was removed chemically. I found a very effective substance to dissolve the wax was an engine degreaser called GUNK. This left a clear surface on the negative model within the resin block. The outer surfaces were then polished so that the finished product was a negative translucent block of polyester resin with a model of the nasal passages and nasopharynx within. Ports were drilled through the block into both nostrils and the nasopharynx. A window was also cut through the posterior wall to allow insertion of measuring instruments (Figure 2).

DISCUSSION

The most difficult and unpredictable part of the modelling procedure was the final step of embedding the wax model in the polyester resin. Polyester resins are very unstable and require curing agents for them to set. Factors affecting setting times are catalyst and activator content of the mixture, the bulk of resin used, the shelf life of the resin, i.e. the loss of monomer by evaporation and the ambient temperature. My experience was that because of the number of variables it was not possible to exactly reproduce previous experiments. Another factor which caused problems was the exotherm produced during polymerization of the resin, leading to internal stresses in the casting with subsequent cracking of the block. Temperature regulation using a cooling jacket to a large extent overcame this problem. Because of the low thermal conductivity of the solid resin, any temperature change instituted should be a very gradual one. After trying several resins I obtained the best results by using a general purpose resin which had not been preactivated. By manipulation of the activator and catalyst content, in relation to the bulk of resin, and allowing for ambient temperature, I achieved results which were generally predictable. Too little catalyst or activator will leave the resin uncured. If the mixture is allowed to come in contact with the wax immediately after activation, the monomer attacks the wax, leaching out any colouring pigment. This leaves a bloom on the inside of the block which is impossible to remove. When removing the wax residue from inside the resin block, it is best to use fresh GUNK and to leave it in contact with the resin only for as long as is necessary to dissolve the wax. Gentle agitation with a suitable bottle brush removes any adherent lumps of wax.

In my literature search I could not find any definitive description on the exact method of constructing a model of the nose. The technique described by Tompsett, in my hands, did not give satisfactory results. The descriptions of modelling techniques by Voss and Egerton were particularly helpful. A thorough reading of the properties and general instructions relating to the resins produced by the various companies, pays dividends. I found information relating to waxes very scanty and it is only by trial and error one acquires the "feel" of the particular wax.

A second positive in wax was prepared in a similar fashion. This was given to a company specialising in acrylic moulding who produced a similar block to the polyester one. Working with acrylic does not lend itself to "amateur" modelling as the equipment necessary is very expensive and the technique specialised. The optical properties of the acrylic are superior to those of the resin. A low melting point alloy metal was tried as a substitute for the wax. This was found unsuitable due to the poor surface finish achieved. I would not recommend it.

In order for the conditions in the model to be dynamically similar to those in the nose, the Reynold's number in each case should be similar. The Reynold's number is a dimensionless quantity used to describe fluid flow. It may be defined as the ratio of the dimensions of the fluid container, fluid velocity and density, to the fluid viscosity. By calculating the Reynold's number for the model I found it to be dynamically similar to that of the real nose. The respiratory cycle can be simulated by either drawing or blowing air through the model.

RÉSUMÉ

Une méthode facilement intelligible de construire un modèle du nez humain est ici décrite. Le modèle creux réproduit exactement les traits principaux de la structure interne des conduits respiratoires naseaux et du nasopharynx. On a trouvé qu'un modèle construit selon cette technique se prête bien aux études de l'écoulement d'air dans le nasopharynx.

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