TUBOMANOMETRY

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Introduction

Tubomanometry is a new clinical exploration method that measures the active transport of gas from the rhinopharynx to the tympanic cavity. The method is based on simultaneous high resolution pressure in the external auditory canal and rhinopharynx, while pressure is applied to the rhinopharynx during a swallowing maneuver. The procedure analyses the function of the velum palatini during swallowing and is able to demonstrate opening disorders of the fibrocartilaginous eustachian tube. It is noninvasive and easy to perform, and provides dynamic images of the function of the velum palatini during swallowing and gas circulation modalities in the fibrocartilaginous eustachian tube.[1] Clinical trials have shown that several pathologies produce significantly different measurement results, and this method offers a new way to perform basic research studies on fibrocartilaginous eustachian tube function and middle ear pressure regulation.[2,3]

Material and methods

Principle of the device

The aim of this procedure is to define the pressure threshold required to open the fibrocartilaginous eustachian tube and to determine the latency between pressure application and tube opening.

The fundamental principle of tubomanometry consists of administration of a calibrated positive pressure into the rhinopharynx, starting at the reflex time of swallowing. This 'over-pressure' initiates the opening of the fibrocartilaginous tube and the subsequent transfer of gas from the rhinopharynx to the middle ear cleft.

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The device is able automatically to detect the initial phase of swallowing and instantaneously to release a gas bolus with a predetermined pressure level (hyperpressure, in the order of 300, 400, or 500 daPa). This gas bolus spreads into the enclosed space formed by the pipe device, nasal fossae and rhinopharynx, which is closed by the patient's velum.

The signal by which the opening of the tube can be determined is obtained in the external auditory canal.

Device

The tubomanometer is composed of:

- a generator of adjustable pressure, connected in an airtight manner to the nasal fossae, and providing controlled positive pressure ranging between 15 and 60 mbar;
- a synchronizer allowing automatic discharge of the hyperpressure, exactly linked to swallowing;
- a detector of tympanic movement, consisting of a pressure transducer tightly connected to the external auditory canal (Honeywell pressure transducer, 0-690 daPa pressure range);
- a pressure transducer (Honeywell, 0-3440 daPa pressure range) for the measurement of pressure in both the nasal fossae and rhinopharynx;
- an electronic processor to analyze the signals provided by the pressure transducers;
- a software package that registers, visualizes, interprets, and stocks the data obtained, making curves.

The apparatus consists of a calibrated pressure generator, and two highly sensitive pressure detectors. Pressure is applied through a tube system which is fitted to the nostrils, and one of the pressure detectors records the pressure in the rhinopharynx. A second tube is fitted in an airtight manner to the external auditory canal, and a second pressure detector measures the pressure in this tube. If pressure enters the middle ear cleft through the fibrocartilaginous eustachian tube, the eardrum will be displaced and a pressure change will be detected in the external auditory canal. The pressure in both the rhinopharynx and the external auditory canal is digitized and stored in a PC. The pressure variations can be observed in real-time on the computer screen. After performing a measurement, the data can be analyzed in both the time and pressure domains, using on-screen cursors. The relevant latencies and pressure values are stored in a patient database, together with the curves recorded.

Directions for use

The patient is seated with eyes in a horizontal direction. The investigation considers the right and left ears in succession. The test itself only takes a few minutes, with no discomfort and a minimum of instructions to the patient. Firstly, an airtight stopper (of the type used in ordinary tympanometry) is fitted in the

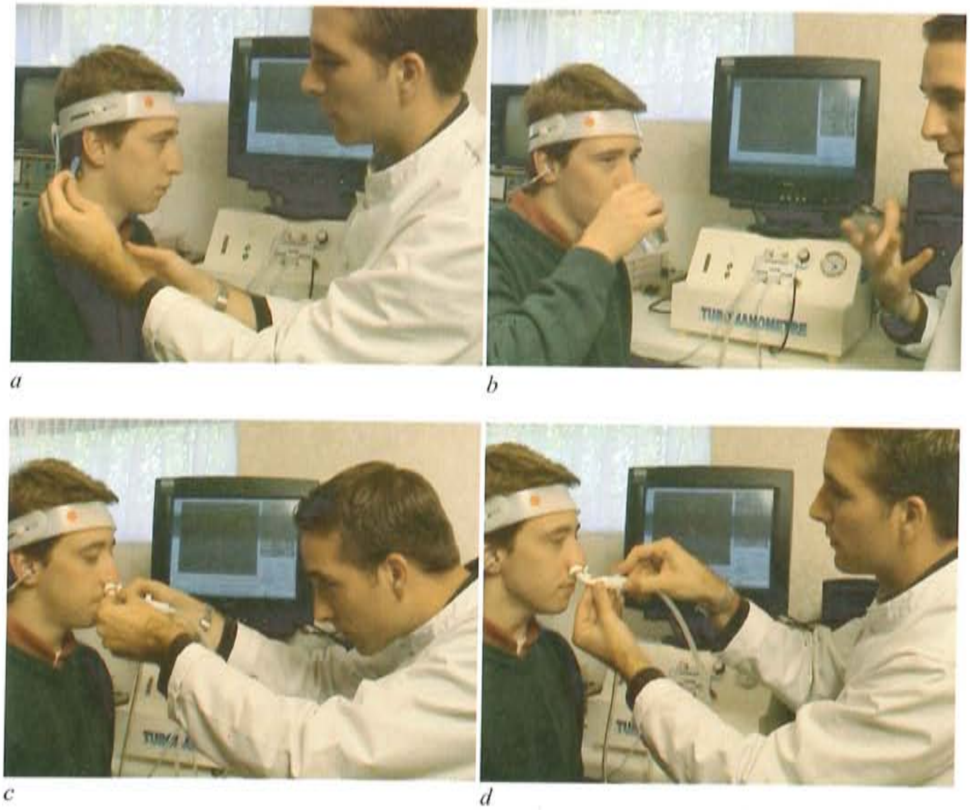

Fig. 1. Tympanometry: directions for use. *a.* An airtight stopper is fitted in the external auditory canal to connect the ear canal pressure detector. *b.* The patient is instructed to take a small amount of water into the mouth. *c.* A two-legged nostril adapter is pressed to the nose so that an airtight fit is obtained. *d.* The patient swallows, keeping the teeth tightly closed.

external ear canal, in order to connect the ear canal pressure detector (Fig. 1a). Then, the patient is instructed to take a small amount of water into the mouth (Fig. 1b): this water helps in the performance of a single, well-controlled swallowing action, which will trigger opening of the fibrocartilaginous eustachian tube. Next, the patient or the examiner presses a two-legged nostril adapter onto the nose, so that an airtight fit is obtained (Fig. 1c). This adapter is connected to the pressure generator and the rhinopharynx pressure detector through a tube. Then, the patient swallows, keeping the teeth tightly closed (Fig. 1d). The swallowing itself triggers the application of pressure to the rhinopharynx: the gas bolus is applied automatically, it spreads into the middle ear cleft spaces, and the opening of the fibrocartilaginous eustachian tube is signalled in the external auditory canal. The actual measurement procedure takes less than one minute, so that several subsequent retests can easily be performed.

Interpretation of the results

An important parameter in this examination is the latency between the application of pressure to the rhinopharynx and the opening of the tube. The opening of the fibrocartilaginous eustachian tube can easily be observed on the external auditory canal pressure curve as a sudden increase in pressure, caused by displacement of the eardrum (Fig. 2: upper curve). The triggering point of the pressure application can easily be determined from the rhinopharynx pressure curve. The triggering itself is caused by the act of swallowing.

Sometimes, in basic investigation work, swallowing is detected using a piezoelectric collar, which is tightly fitted to the neck: the swallowing action deforms the collar, which generates an electric triggering channel. Although a very good trigger signal can be obtained in this way, many patients find such a collar unpleasant and oppressive.

Therefore, in clinical tubomanometry, the trigger is obtained in a different way. The swallowing action itself causes a subtle change in rhinopharynx pressure. This change is detected by the highly sensitive pressure detector, and is used as a triggering signal to start the application of pressure. The pressure generator is developed in such a way that a gas flow can be obtained while keeping the pressure constant, so that the desired pressure value is obtained almost immediately in the rhinopharynx cavity. This is the result of the difference between the volume of the reserve (two liters) and that of the rhinopharynx cavity. Shortly after the application of pressure, the fibrocartilaginous eustachian tube will open (in normal cases).

In the case of a perforated drum, the full pressure value present in the rhinopharynx can also reach the external auditory canal. If the tube actually opens over its full length, we should be able to measure the full value of the applied pressure. However, if only a peristaltic motion is present, and only a fixed quantity of gas is injected into the middle ear cleft, we would only expect to be able to measure a limited pressure increase. The pressure increase in the middle ear cleft will cause displacement of the eardrum. This displacement will cause a tiny pressure increase in the closed external auditory canal. The magnitude of this increase depends on the compliance of the eardrum, as well as on the total volume of the ear canal, the pressure transduction tube, and the internal volume of the pressure detector. The two latter factors have an effect on duration P2-P1, but only little on the amplitude. Theoretically, this amplitude also depends on the caliber of the circuit of measurements of the tubomanometer, but experiments have shown that this has little effect compared to the compliance of the eardrum. Due to all these factors, the amplitude of the changes in external auditory canal pressure is pertinent for tympanic membrane retraction pockets and for eardrum perforation. However, thanks to the well-defined triggering point, measurements of latency are highly accurate. Clinical studies have shown that latency is a very significant parameter in distinguishing between different pathologies.[3]

Finally, the pressure in the rhinopharynx is measured. The main purpose of this is, of course, to determine the triggering point of pressure application, which is used to measure latencies. However, in some cases, there is a leak in velum closure, so that the predetermined pressure value cannot be fully obtained in the rhinopharynx. In such cases, the amplitude of the rhinopharynx pressure curve becomes clinically relevant. On the one hand, it presents an indication of the amount of leakage. On the other, the pressure curve is necessary to avoid erroneous conclusions regarding tubal malfunction: if the pressure value obtained in the rhinopharynx is not high enough, the fibrocartilaginous eustachian tube will not open and no pressure signal will be obtained in the external auditory canal, although tubal function may be in perfect condition.

Several clinical studies have been undertaken, and an overview of the outcomes is provided in the next section.[2,3] The tubomanometer apparatus is currently also being examined as a new tool for basic research studies, since it may be able to provide new information on the dynamics of fibrocartilaginous eustachian tubes and middle ear cleft pressure regulation.

Using the curves obtained with the tubomanometric procedure, swallowing and opening of the fibrocartilaginous eustachian tube, and middle ear cleft pressure variations balance, can be analyzed.[4,5] This technique, which is noninvasive and easy to perform, provides dynamic images of the function of the velum palatini during swallowing, as well as gas circulation modalities in the fibrocartilaginous eustachian tube and tympanic cavity. It offers a new method for studying the active transport of gas from the rhinopharynx to the tympanic cavity.

Results

In the current text, we indicate all pressure values in Pascals. In clinical practice, the mBar is often used, where 1 mbar equals 100 Pascals, or 10 daPa. The tubomanometric test provides dynamic pressure/time curves at the level of both the rhinopharynx and the external auditory canal (Fig. 2). The X axis shows the time values (sec); the Y axis quantifies the pressure (mbar).

The data obtained appear in the form of two coupled curves:

- the inferior curve shows the values of the positive pressure imposed in the rhinopharynx, which is intended to provoke the opening of the fibrocartilaginous eustachian tube;
- the superior curve represents the pressure variations at the level of the external auditory canal, resulting from the movements of the tympanic membrane, which in turn are the result of the pressure variations in the tympanic cavity, after opening of the fibrocartilaginous eustachian tube.

Inferior curve: information on the rhinopharynx

Analysis of the inferior curve shows three successive phases (Fig. 2):

- The initial phase corresponds to the *rise in pressure*: from point C1 to point C2. This rise corresponds to closure of the velum (soft palate), and expresses the increase of pressure into both the nasal fossae and rhinopharynx. This part of the curve represents the stimulus which enables tubal opening (C2 in mbar), and corresponds to the start of the reflex stage of swallowing. When C2 is more than 10% inferior to the pressure applied, closure of the velum is insufficient. The time lapse between C1 and C2 (in seconds) indicates the time that is necessary to obtain the positive pressure. This should be as short as possible and, in any event, less than < 0.30 seconds.
- The second phase indicates the '*pressure plateau*': from C2 to C3. It shows individual variations, and also varies for the same subject. It is the result of the isometric contraction of the muscles of the velum.
- The third phase starts at C3 and shows a marked *decrease in pressure* in the rhinopharynx. This fall is due to relaxing the velum muscles and restoring the gasway.

Superior curve: information on the external auditory canal

Pressure variations at the level of the external auditory canal are the result of movements of the tympanic membrane, corresponding to pressure variations in the tympanic cavity, after opening of the fibrocartilaginous eustachian tube.

When the eardrum is perforated (tympanic perforation or ventilation/aeration tube), the values recorded are the variations in intratympanic pressure. However, in normal cases, only a small pressure increase is recorded, due to the volume displacement of the eardrum into the closed ear canal.

The superior curve shows also three phases (Fig. 2):

- An '*increase in pressure*' phase: from P1 to P2. This phase corresponds to the lateral movement of the tympanic membrane, in response to the increase of pressure in the middle ear cleft.
- The '*upholding of the pressure*' phase runs from P2 to P3. This appears as a horizontal line that corresponds to maximum displacement of the tympanic membrane. The duration of this plateau corresponds to the duration of the application of positive pressure into the rhinopharynx. It has been demonstrated by experiments in the flow mode that the fibrocartilaginous eustachian tube is open and allows gas transfer during this plateau.
- The '*emptying of the middle ear cleft*' phase runs from P3 to P4. This is the decrease in pressure in the tympanic cavity.

Standards

The function of the fibrocartilaginous eustachian tube, and more particularly, the start of its opening:

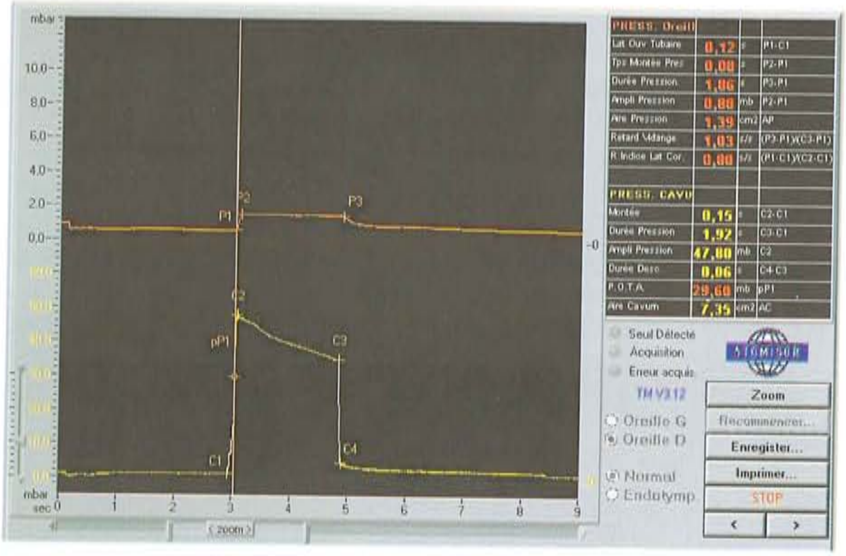

Fig. 2. Tubomanometry curves. The upper curve shows the pressure variations at the level of the external auditory canal as a result of the movements of the tympanic membrane consecutive to the pressure variations in the tympanic cavity, after opening of the fibrocartilaginous eustachian tube. The inferior curve shows the positive pressure introduced in the rhinopharynx, intended to provoke the fibrocartilaginous eustachian tube to open.

R: constitutes the ratio between the latency of tubal opening (P1-C1) and the time of increasing pressure in the rhinopharynx (C2-C1). Both values are expressed in seconds:

$$R : \frac{P1\text{-}C1}{C2\text{-}C1} = 0.87$$

(this corresponds to standard values in normal subjects)

This ratio is an expression of the reactivity of both the fibrocartilaginous eustachian tube and velum to the stimulus imposed. The R value allows the moment of opening of the fibrocartilaginous eustachian tube to be located:

if $R < 1$	:	opening takes place before C2
if $R > 1$	:	opening occurs after C2
$R \sim = 0$	:	patulous fibrocartilaginous eustachian tube

When the R value cannot be calculated, this indicates that the fibrocartilaginous eustachian tube has not opened.

The tympanic response:

– P2-P1 (sec) corresponds to the time required for lateral movement of the tympanic membrane, in response to the increase of pressure in the middle ear cleft. This occurs between opening of the tube and stabilization of the pressure in the middle ear cleft.

Normal mean values on the time and pressure axis:

- P2-P1 = 8.6 daPa corresponds to the amount of pressure transmitted to the external auditory canal during displacement of the tympanic membrane following opening of the fibrocartilaginous eustachian tube. This value does not vary with the various stimuli (hyperpressure level of 30, 40 or 50 mbar). A shorter value appears to be correlated with a small middle ear cleft volume (mastoid air cells system and tympanic cavity). This value is far lower than that in the middle ear, because of the compliance of the eardrum.

- $\frac{\text{P3-P1 sec}}{\text{C3-P1 sec}} = 1.41$ this ratio is a measure of the total opening time of the fibrocartilaginous eustachian tube, compared to the mean duration of swallowing, after tubal opening.

Emptying of the middle ear cleft is indicated by the decrease in pressure in the external auditory canal that occurs starting from point P3 (closure time of the fibrocartilaginous eustachian tube). This process is attributed to gas resorption through the middle ear cleft mucosa and/or an expression of the buffer power of the middle ear cleft.

Acknowledgments

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References

1. Estève D, Martin C, Dubreuil C: Tubomanométrie: aspects de la fonction équipressive de la trompe auditive: cas cliniques. J Fr ORL 48:6, 1999
2. Estève D, Dubreuil C, Della Vedova C, Normand B, Martin C: Evaluation par tubomanométrie de la fonction d'ouverture tubaire et de la réponse tympanique chez le sujet normal et chez le sujet porteur d'une otite séro-muqueuse chronique: comparaison des résultats. J Fr ORL 50(5):223-231, 2001
3. Estève D, Dubreuil C, Della Vedova C, Normand B, Lavieille JP, Martin C: Physiologie et physiopathologie de la fonction d'ouverture de la trompe auditive: apports de la tubomanométrie. J Fr ORL 50(5):233-241, 2001
4. Ars B, Ars-Piret N: Middle ear pressure balance under normal conditions: specific role of the middle ear structures. Acta Oto-Rhino-Laryngol Belg 48:339-342, 1994
5. Ars B, Ars-Piret N: Morpho-functional partition of the middle ear cleft. Acta Oto-Rhino-Laryngol Belg 51:181-184, 1997