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Computer simulation of human tympanic membrane

AVINASH BHIDE, M.S. (Pune, India)

Abstract
Because of the difficulties in studying the mechanical properties of the human tympanic membrane *in situ*, structural data from the cadaveric tympanic membrane samples is used for simulation of the surface structure of the tympanic membrane with the help of a computer. The hitherto poorly understood contour of the tympanic membrane is available for the development of a tympanic membrane and middle ear model.

Introduction

In 1868, Helmholtz postulated that the important part of the sound transformer mechanism resides in the tympanic membrane itself, and that it had to do with the mechanism of a curved membrane. Subsequent authors concentrated their attention on the acoustic properties of the tympanic membrane (TM). While the tympanic membrane contour remained poorly understood, the shape of the TM was described by Helmholtz (1868) and Kirikae (1960).

The mode of the vibration of the tympanic membrane was studied by von Békésy and Rosenblith (1951) and Konradsson *et al.* (1987). Tondorf and Khanna (1970) suggested that the mode of sound transmission by the tympanic membrane is complicated and they did not agree with von Békésy who had suggested that the tympanic membrane was a stiff plate hinged around the trans-ossicular axis. The tympanic membrane converts a wide range of airborne sound waves into ossicular vibrations. This is its most important assigned function. When subjected to abnormal pressures, the tympanic membrane shows deformations such as retractions, tears and perforations. Clinical observation suggests propensities of particular parts of the tympanic membrane to certain lesions, such as retraction of the membrane in the posterosuperior quadrant (PSQ). Bhide (1977) had suggested that the PSQ is a structurally weak area because of its curvature which has a longer radius compared with those of the other quadrants. Dirckx *et al.* (1988) proposed and demonstrated the reconstruction of the surface of a silastic cast of a cat TM using shadow moiré contouring by an optical interference method. However, this methodology has not been used in the human TM. Obviously it is difficult to study the mechanical properties of the human TM *in situ*. The surface structure contour simulation with the help of a computer is attempted, and the details are presented.

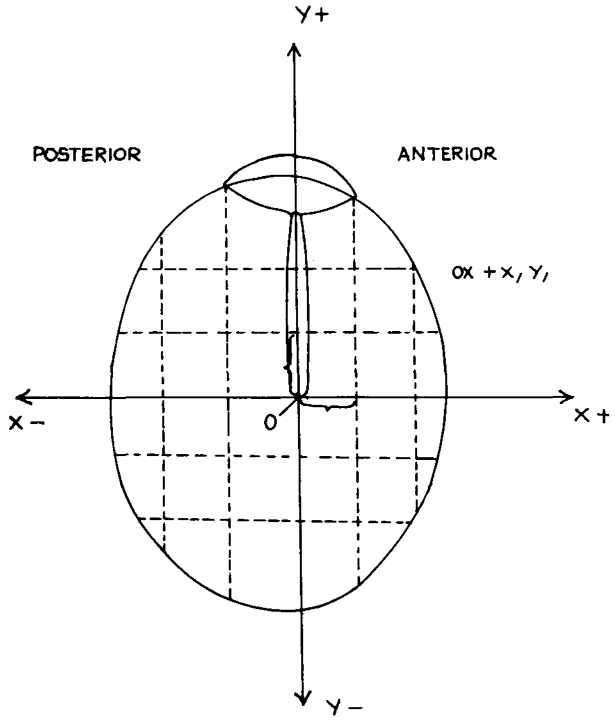

FIG. 1
A schematic diagram of the tympanic membrane shows grid of points on XY co-ordinates.

Materials and methods

Study samples—Ten normal tympanic membranes—six from left and four from right ears— each attached with the malleus and its annular edge secured in the sulcus tympanicus of the bony wall, were dissected from human temporal bones within 48 hours of death. The specimens were stored in 2.5 per cent gluteraldehyde solution; glutaraldehyde crosslinks protein wall. It halts all cytoplasmic movement and stabilizes the cell wall and morphology and hence it is the fixative of first choice (Hopwood, 1973).

Scanning of the samples—The specimens were scanned under a dissecting microscope to determine the X, Y and Z co-ordinates for a grid of points as illustrated

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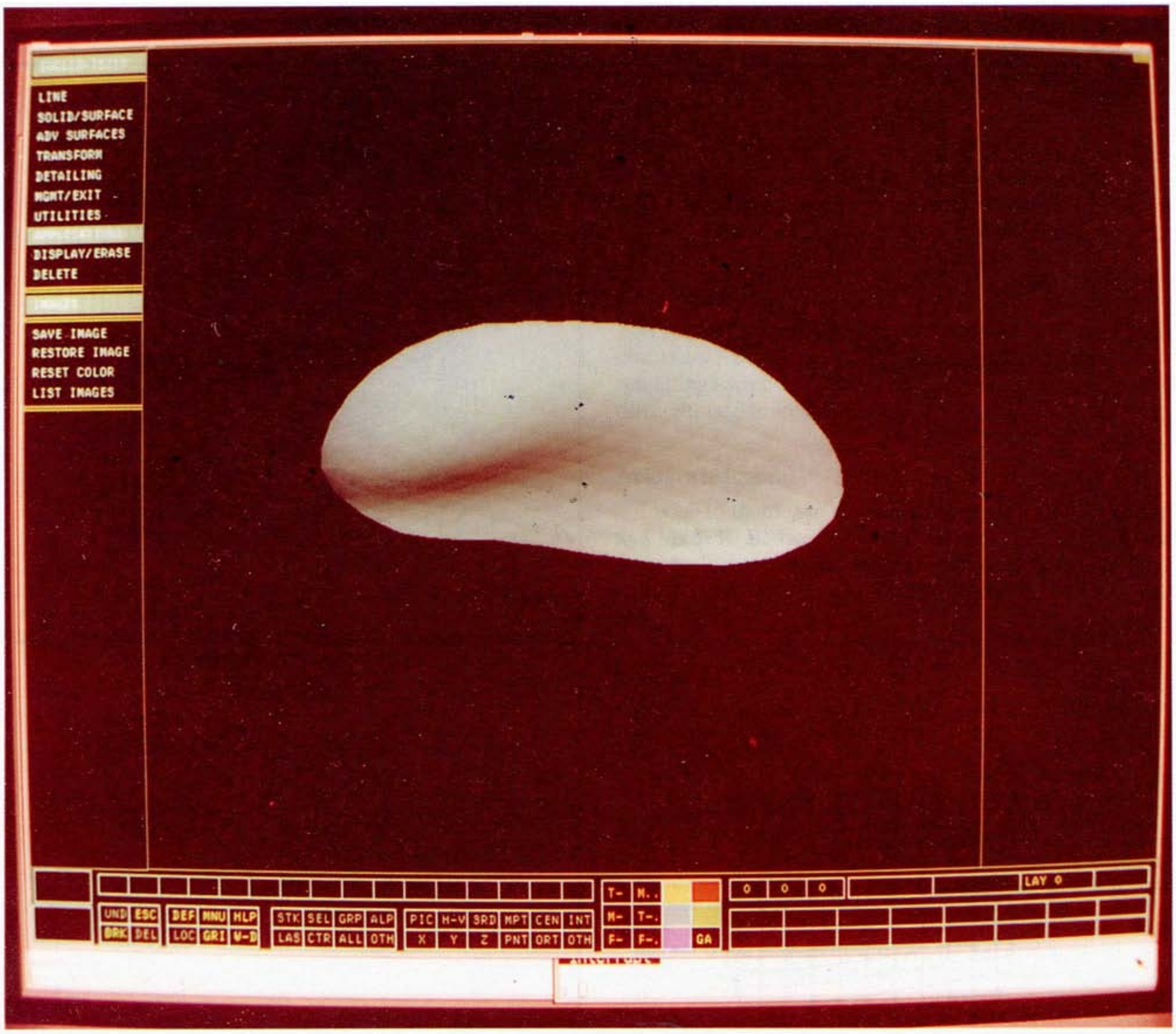

FIG. 2

Computer generated tympanic membrane surface (patch).

in Figure 1. The readings in the anterior half, were supposed to be X+ and in the posterior half X−. Since the edge of a tympanic membrane is not in a single plane, each specimen was rotated through 180° around the Z axis passing through point 0, corresponding to the umbo. The average reading at each point was used in the data to minimize errors.

Computer modelling—This was done on VAX station (VS 3200 designer workstation) using Euclid Computer Aided Engineering (CAE) software from Matra Data Vision, France. This software is used for precise modelling and manufacturing of mechanical engineering designs.

Co-ordinate data for points was entered for each case. The co-ordinates along one direction were fixed, for example posterior half as $X = -1$, $X = -2$, umbo as $X = 0$, and anterior half as $X = 1$, $X = 2$. Y and Z co-ordinates varying and smooth curves, were fitted to pass through these points. Subsequently, a surface was generated using the fitted curves.

The surface figure was trimmed using an elliptical cylindrical surface to arrive at the final shape and orientation of the tympanic membrane. The elliptical cylindrical surface was generated with X axis being 8.5 mm and Y axis being 9.5 mm (Fig. 2).

The computer generated tympanic membrane surface (patch) was seen at various eye positions and rotated around the three axes to verify that all the features were modelled faithfully (Fig. 3). One case was at variance from the other specimens and was excluded from further analysis.

Loci of identical values of radii of curvature were joined to generate a contour loop diagram of the tympanic membrane (Fig. 4).

Section planes were placed in various orientations parallel to the canal as well as diagonal to it, and intersection curves of the patch between the section planes were obtained as seen in Figure 5.

Radii of curvature were computed at fixed intervals along the intersection curves. Plots with radii of curvature superimposed on each intersection curve were drawn (Fig. 5).

Discussion

From acoustic and clinical points of view, the TM is

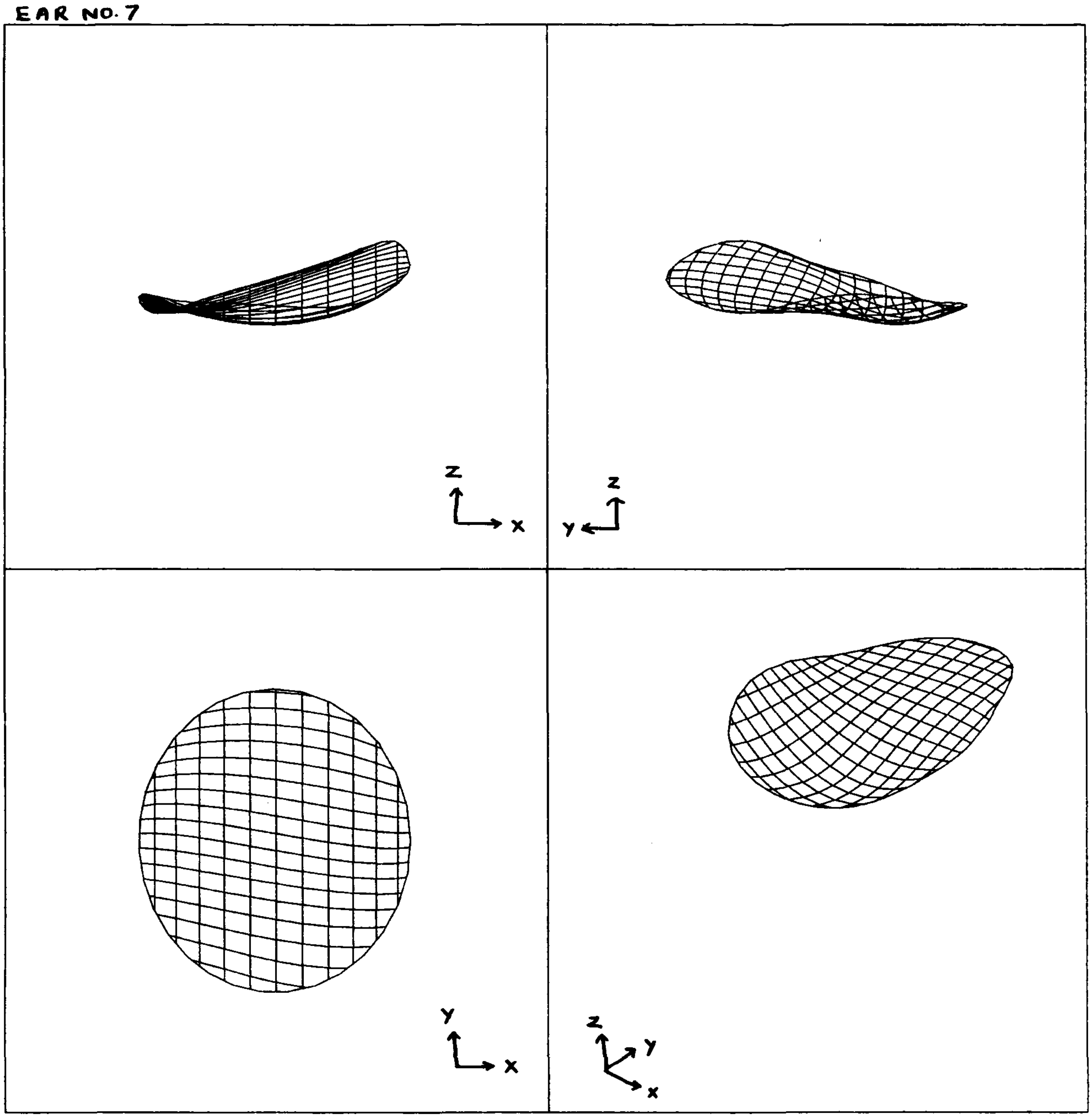

FIG. 3

Shows the reconstructed tympanic membrane as it is seen at various visual angles (eye positions).

considered like a plane diaphragm. In reality the TM has a unique surface and contour which is still unclear.

Chalat (1980) stated that it was difficult to explain several phenomena occurring in the tympanic membrane with the present understanding of its structure. According to Funnel and Laszlo (1982), the mechanical role and properties of the TM are poorly known.

The contour of the tympanic membrane has remained ambiguous, but what gives rise to the peculiar contour can be understood. In the case of the tympanic membrane, the supports or mountings are more complicated, in that the membrane is fixed in the sulcus tympanicus in a skew fashion as it is not in one plane. This situation is further complicated by the attachment of the handle of the malleus to the TM. With the paucity of knowledge of many factors responsible for the peculiar structure of the TM, cadaveric samples preserved in gluteraldehyde were used for acquiring the data consisting of X, Y, Z co-ordinates, which were fed to the computer.

Tympanic membrane surface (Figs. 2 & 3)—The tailored patch when seen from different visual angles (eye positions) shows similarity with the real tympanic membrane.

Figure 4 shows a contour plot of the tympanic membrane. Each loop is formed by a line joining the set of loci of identical radii of curvature. From the central portion (point 0 = umbo), the magnitudes of the radii gradually change towards the periphery. Then there is an encircling zone where the curvature does not change for considerable width. The outer area shows reversed curvatures.

Intersection curves and the radii of curvature—Figure

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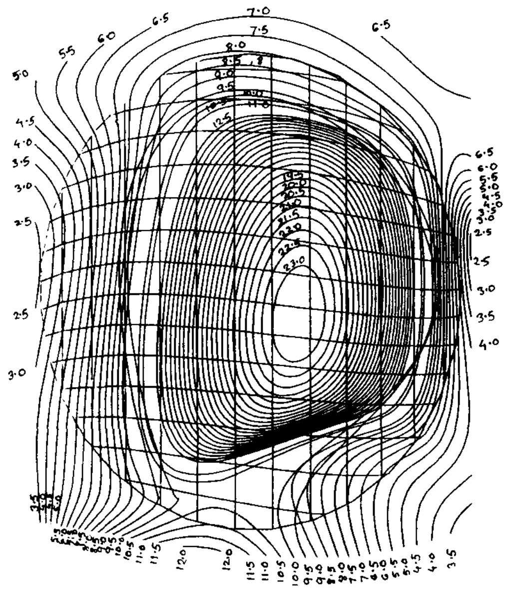

Fig. 4

Shows the contour loop diagram consisting of encircling loops and reversed curvatures.

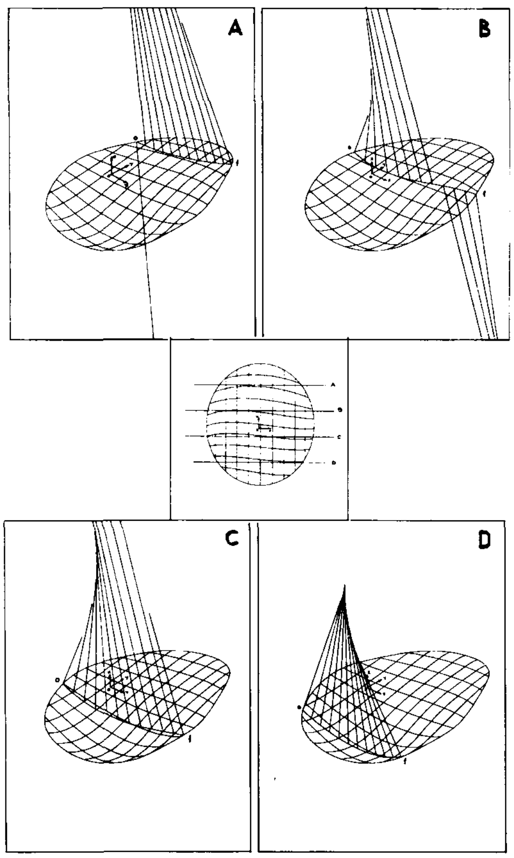

Fig. 5

Shows the length and the directions of the radii at horizontal sections of the tympanic membrane. The radii of curvatures in the opposite direction suggest an anticlastic surface characteristic of the tympanic membrane.

5 shows radii of curvatures in horizontal sections. The radii are of different lengths. They are in the opposite direction suggesting the anticlastic nature of the surface.

Application and scope

1. Development of a TM and middle ear model.
2. To study the process of generation of deformities in TM, such as refractions, tears and perforations.

Conclusion

A human tympanic membrane is situated in more than one plane. It has an anticlastic surface because of its mountings which divide the membrane into segments of different curvatures and widths.

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Address for correspondence:
Dr Avinash Bhide,
'Ashwini',
Vijayanagar, 2108,
Sadashiv Peth,
Sane Guruji Road,
Pune 411030,
India.
Fax: 212-44 4253

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