STUDIES IN ULTRASONIC ECHOENCEPHALOGRAPHY—VII: GENERAL PRINCIPLES OF RECORDING INFORMATION IN ULTRASONIC B- AND C-SCANNING AND THE EFFECTS OF SCATTER, REFLECTION AND REFRACTION BY CADAVER SKULL ON THIS INFORMATION*

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Abstract—Some of the factors are considered upon which the presentation of intracranial tomograms by the ultrasonic pulse-echo technique depend. Range resolution is degraded by the increased velocity of the ultrasonic beam in the skull. Azimuth resolution is degraded by refraction when the beam does not strike the skull at normal incidence. Both range and azimuth resolution are degraded for strong reflectors when receiver sensitivity is high. The limitations imposed by these factors on the angle of scan and dynamic range of the receiver system are estimated.

1. INTRODUCTION

Since A-scan echoencephalography became accepted as a method of determining the position of the cerebral mid-line it has been natural that attempts should be made to adapt the technique to the B- or C-modes of scanning, not only in order to demonstrate the mid-line structures better but also in an endeavour to outline the ventricular system and possibly other intracranial structures. The original development of such a technique is ascribed to Howry and Bliss who, in 1952, published a pictorial cross-section of the forearm and other structures. Wild and Reid, also in 1952, working at the relatively high frequency of 15 MHz, were able to produce a two-dimensional picture of the intact human breast. The interest in such a technique was greatly stimulated by the successful development for clinical purposes of two-dimensional ultrasonic scans in the abdomen by Donald, MacVicar and Brown in 1958 and in the eye by Baum and Greenwood in the same year.

Early two-dimensional scanners for use specifically on the head were developed by Greatorex and Ireland (1964), de Vlieger et al. (1963) and Makow and ourselves. More recently, with the introduction of a B-mode facility in several commercially-available machines, a large number of investigators have reported their clinical experience with linear B-scans. Although many of these devices appear to be capable of demonstrating the cerebral mid-line, no reliable ventriculograms or representations of the intracranial structures have yet been produced by any group of workers.

The ability of a B-scan or a C-scan to produce tomograms depends upon three basic functions. Firstly, the presentation system must be capable of receiving and recording a sufficient number of returning signals or echoes when a system is used depending on reflected pulses. Secondly, these returning echoes must be topographically presented without undue distortion and thirdly, the system must be capable of resolving echoes from neighbouring structures as discrete and

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separate entities. Each of these three functions will be considered separately with particular reference to the effect upon them of the passage of the ultrasonic beam through cadaver skull.

2. METHOD

The skulls used were obtained from fresh cadavers at the time of autopsies, usually within a few hours of death. Care was taken to ensure that the skulls did not dry out. They were exposed to air only for the short period taken to form moulds with them, from which plaster skull caps were then made for replacement in the cadaver for cosmetic purposes. They were kept in a solution of formalin for storage and when in use formalin was added to the water in the bath, forming a weak solution. We used the skulls for varying periods of from a few weeks to several months. While it is possible that the acoustic properties of the skull vary with age and the degree of formalization, day to day variations, or even week to week variations, were insignificant and repeated plots at intervals of a few weeks showed good equality.

All ultrasonic fields were generated by a Smith barium titanate transducer, the crystal being 2 cm dia. Its resonant frequency was rated as 1.5 MHz. For a transducer of these dimensions the far field should start 10 cm from the transducer. The transducer was driven by a Smith Mark 7 flaw detector at a pulse repetition frequency of 150/sec. The receiving system comprised a Glennite UP/800 C probe with a Hewlett-Packard Model 450A amplifier and a Tektronix 564 oscilloscope fitted with a type 3A1 Y-amplifier.

The Glennite ultrasonic probe had a barium titanate cylinder \( \frac{1}{16} \) in. dia. and \( \frac{1}{8} \) in. long. Its response in the horizontal and vertical planes is shown in Fig. 1. All measurements were made after the probe was rotated in its longitudinal axis until a maximal signal was obtained. The directional loss of sensitivity as the probe was moved away from the central axis of the ultrasonic beam was considered insignificant for the angles we used. The frequency response of this probe was only constant to 0.1 MHz and became quite variable at and above 1.0 MHz.

![Fig. 1. Two polar diagrams of voltage response of the receiving probe at 1.5 MHz. On the left the plot is for the plane perpendicular to the longitudinal axis of the probe and through the centre of the probe (plane \( X, X' \)). On the right the plot is through the longitudinal axis in the plane \( A A' \).](image-url)