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ABSTRACT

In B-mode scanning with single-probe systems, the lack of detection of echo pulses returning off-axis leads to image degradation. An array consisting of 18 receiving elements arranged in annular fashion about a central emitter probe has been constructed in an effort to improve visualization of tissue interfaces through the detection of off-axis echo pulses. Images of test objects in a water bath have been obtained with the array. The array has also been tested as adapted for patient scanning by means of a deformable membrane enclosing a water bath adjacent to the array elements. Using the array, scans of improved detail compared to single-probe scans were attainable.

INTRODUCTION

Contemporary ultrasonic equipment used in medical imaging employs pulse-echo techniques to obtain data which is then processed electronically, ultimately yielding a two-dimensional representation of a given cross-section through a patient's body. In a typical pulse-echo imaging system, a single hand-held piezoelectric transducer is positioned at a point on the patient's body. The transducer is excited by repetitive voltage pulses, each of which causes the emission of an ultrasonic beam. When the ultrasonic beam strikes interfaces of differing acoustical impedance within the body, part of the emitted ultrasonic energy is reflected, with the angle of reflection equal to the angle of incidence at the interface. The single transducer probe functions as a detector following the propagation of an emitted pulse and the detection of returned echo pulses is the basis for the creation of the two-dimensional B-scan. A major problem with the utilization of a single probe as both emitter and receiver is that only those tissue interfaces which are very nearly perpendicular to the axis along which the beam is generated can be detected. If a tissue interface struck by an ultrasound beam is inclined at more than a very few degrees from absolute perpendicularity to the emitted beam, the echo pulse will be reflected to a point at some distance from the emitting transducer and will not be detected. (1)

An annular array of detector elements concentric to a central emitter probe should be capable of detecting reflected ultrasonic pulses more efficiently, ultimately producing a more accurate image of acoustic interfaces within the body. The basic principle involved is illustrated in Figure 1, in which an off-axis echo pulse not detectable at the central probe is recorded by a transducer in an annular receiving array. Various array configurations of this general sort have been constructed in an effort to resolve interfaces having a relatively wide range of angulation with respect to the incident ultrasonic beam (2,3). The design of an annular array for use in B-mode scanning, and results of testing the array in a water bath and as adapted for future use in patient scanning, will be described.

DESIGN OF THE ARRAY

As indicated above, the array design consists of a central emitter probe surrounded by an annular array of transducers functioning only as detectors. The central probe used is a 2.25 MHz, 19 mm diameter commercial transducer with long internal focus. Piezoelectric disks (.750 inch diameter PZT - 5A discs, resonant at 2.25 MHz) were appropriately matched and backed for use as receiver elements. (4) These receiver elements were then mounted in phenolic plastic material, in an annular arrangement concentric to the central emitter probe. Six receiver elements are present in an inner ring, twelve in an outer ring as shown in figure 2.

IMAGING OF TEST OBJECTS WITH THE ARRAY

The annular receiving array was connected to a switch box having switches for each of the 18 receiver discs, and was affixed to a Picker Echoview 8 ultrasound machine as shown in figure 3. With the ultrasound machine in "thru" mode, appropriate electrical connections were made to employ the array elements as receivers and the central probe as emitter. Using "search" mode, the central probe could alternately be used as both emitter and receiver to produce comparison single-probe images of test objects. The array was affixed to a lucite bar which slid in a grove in the top of a water bath in which images of test objects were obtained. The method and results of imaging several test objects in the water bath are described below.

Initial images were obtained with a brass plate which could be angled along an axis, with angulation read off an affixed protractor. Using the single probe as emitter and receiver, the plane was adjusted for maximum transducer response using A-mode. Using B-mode, it was then determined that the plane, positioned 10 cm. from the tip of the central probe could be detected when angled up to 8 degrees on either side of the maximum response position when using the single probe as both emitter and receiver. Using the same output and gain settings for B-mode scanning, the plane could be detected when angled up to 18° on either side of maximum by using the central probe as emitter and the array elements as detectors, alternately switching in each of the receiver discs in 18 successive passes over the plane. Subsequent B-mode of the test objects in the water bath were obtained in this manner of successively switching in individual transducer discs as receivers, while performing multiple passes over a test object.

A latex rubber "cyst" phantom 6 cm. in diameter and containing sucrose solution was made and scanned using both the single-probe technique and employing the array elements as receivers. Gain and output settings were the same for both scans which are shown in Figure 4. The scan performed using the array demonstrates more of the "cyst" wall diameter. A fresh human kidney was suspended in the water bath in a gauze support and scanned using both the single probe, and the array elements as receivers. Images obtained via these two techniques, at the same output and gain settings, are shown in Figure 5. More tissue interfaces of the kidney were visualized using the array elements as receivers. The scans made with the array record the kidney surface as a series of lines several millimeters long as compared to the well-defined points recorded using the single probe.

In order to adapt the array for patient scanning, it is necessary to enclose a water bath adjacent to the array elements with a deformable membrane which can be scanned over a patient's surface. To test the feasibility of this arrangement, a water bath adjacent to the array was enclosed by a thin latex rubber membrane and scans were obtained of an anencephalic fetus in a specimen case by passing the latex-enclosed water bath over the surface of the case. Electronic circuitry which provided automated successive switching among the receiver elements was employed for this application (4). Single-probe and array scans were obtained at the same output and receiver gain settings and are shown in Figure 6. More detail of some portions of the fetal anatomy visible in the scan made using the array elements as receivers.

Discussion

The results of imaging the brass plate which could be angled with respect to the incident ultrasonic beam give an indication of the advantage of the annular array of detectors over a single probe in visualizing interfaces angled away from perpendicularity to the incident beam. Interfaces, such as the brass plate, angled considerably further from perpendicularity to the incident ultrasonic beam are detectable with the array elements used as detectors, compared to the single-probe technique. The ability of the array to image interfaces having a relatively wide range of inclination with respect to the incident beam led to improved visualization of portions of the various tests objects, compared to that attainable with single-probe technique.

When the array elements are used as receivers, an object's surface is recorded as a series of lines, each several millimeters long. This appearance may result from the recording of those portions of an interface detectable by the array through finite excursions (of several millimeters each) of the emitted beam as a scan is performed, and modification of the incoming pulse responses by the electronics of the Picker machine.

Imaging the fetus in a specimen case with the array as adapted for patient scanning indicates the feasibility of using an enclosed water bath. Compared to single-probe scans, images obtained using this arrangement do not show spurious echoes which might be attributed to internal reflections within the water bath. Clinical imaging with the array should be made feasible by passing the membrane-enclosed array across a patient's surface. It is hoped that the improvement in resolution of interfaces angled away from perpendicularity to the incident ultrasound beam, as demonstrated with test objects, will lead to improved quality of clinical images and decrease the need for sector scanning.

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Legends

Figure 1: Principle of the detection of off-axis echo pulses with an annular array. An echo pulse arising from an interface angled with respect to the incident ultrasonic beam is detected by an element of an annular array of transducers used as receivers.

Figure 2: Transducer array. The central probe, a commercially obtained, focussed transducer acts as an emitter only, while the 18 surrounding transducer discs are used as receivers.

Figure 3: Experimental set-up. The array is fixed to the "arm" of a standard ultrasound machine and scans test objects in the water bath at right.

Figure 4: Scans, taken at the same gain settings, of a 6 cm. diameter latex rubber "cyst" phantom. The scan performed using the array elements as receivers (below) shows more of the "cyst" wall than the scan obtained using a single probe as emitter and receiver (above).

Figure 5: Scans of a human kidney suspended in a water bath performed using the single-probe technique (above), and the array elements as receivers (below). More of some portions of the kidney architecture can be seen using the array elements compared to the single-probe scan taken with the same gain settings.

Figure 6: Scans of an anencephalic fetus in a water bath taken using a single probe (middle), and the array adapted for clinical use as described (below). More fetal anatomy is visualized using the annular array of transducers as receivers (same gain settings used for both scans).

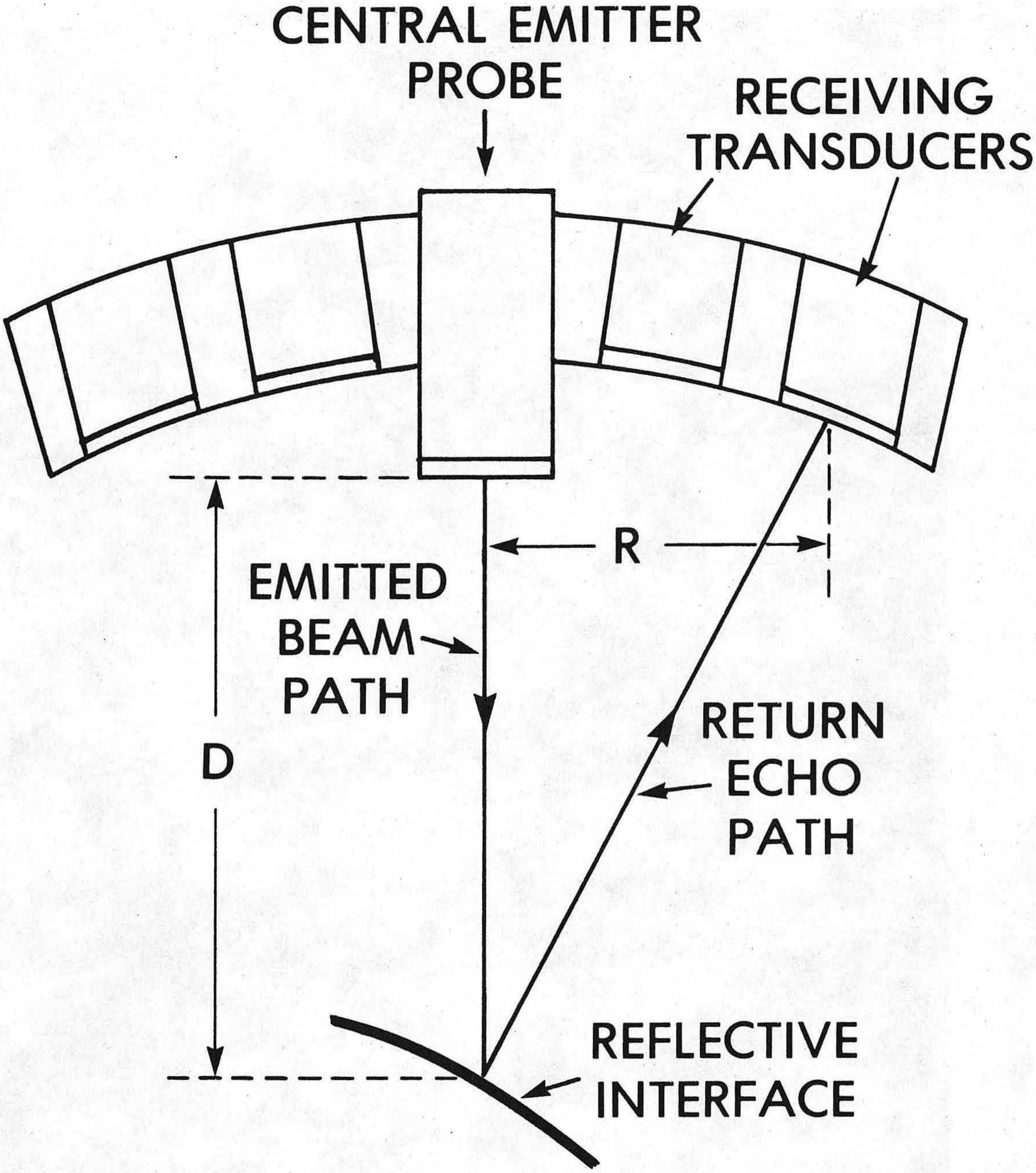

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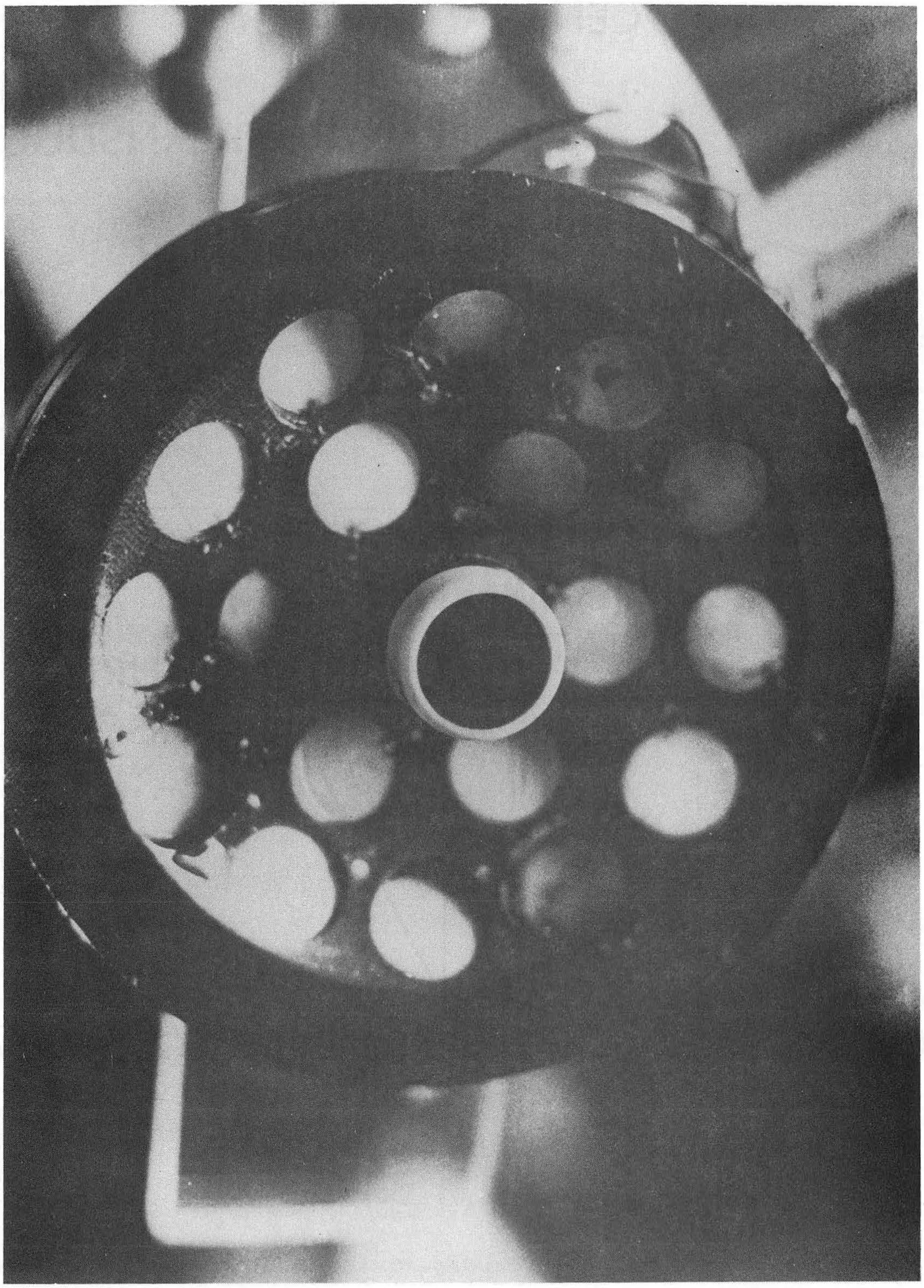
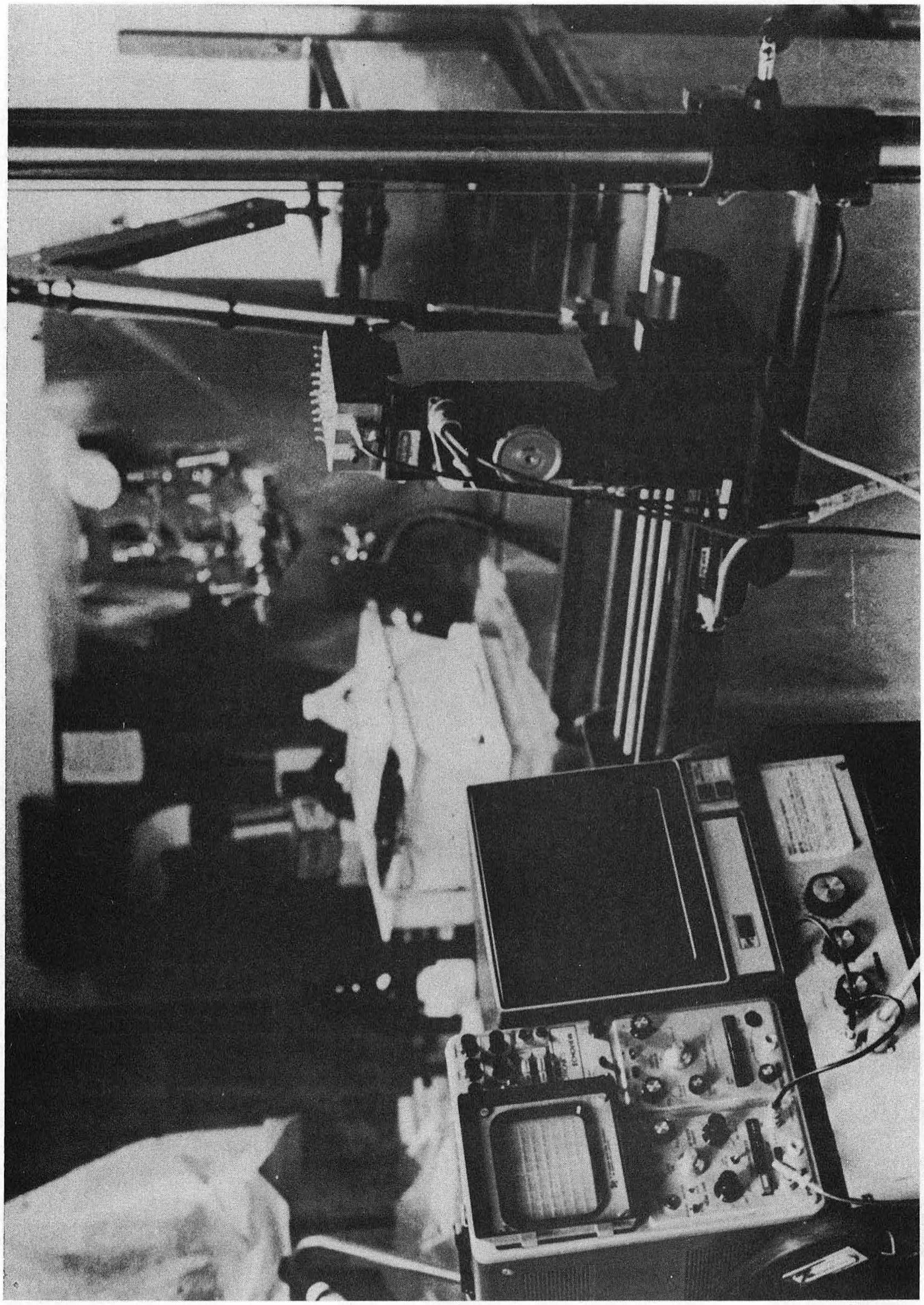
Fig. 1



XBB 770-10417

Fig. 2



XBB 770-10418

Fig. 3

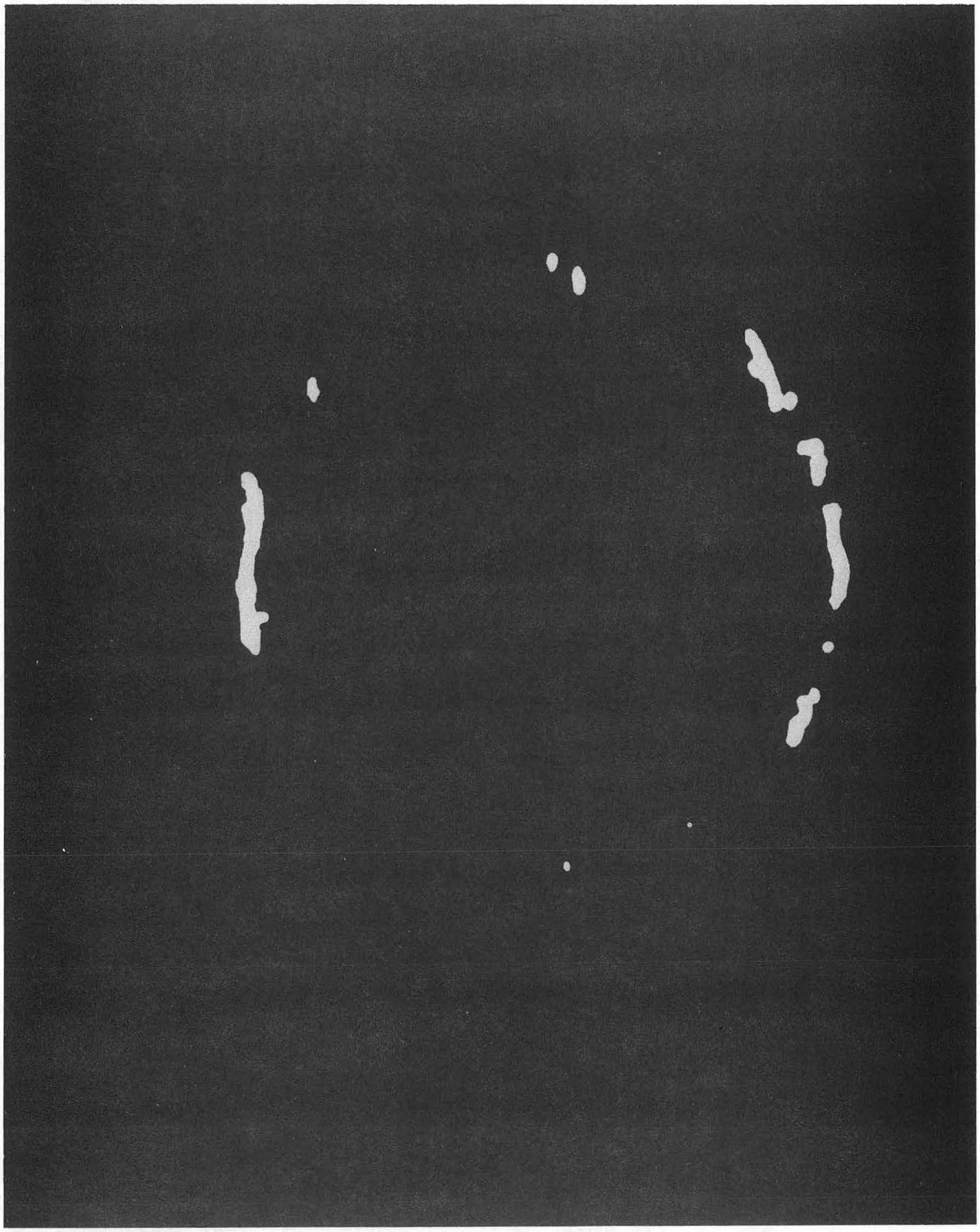


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Fig. 4a

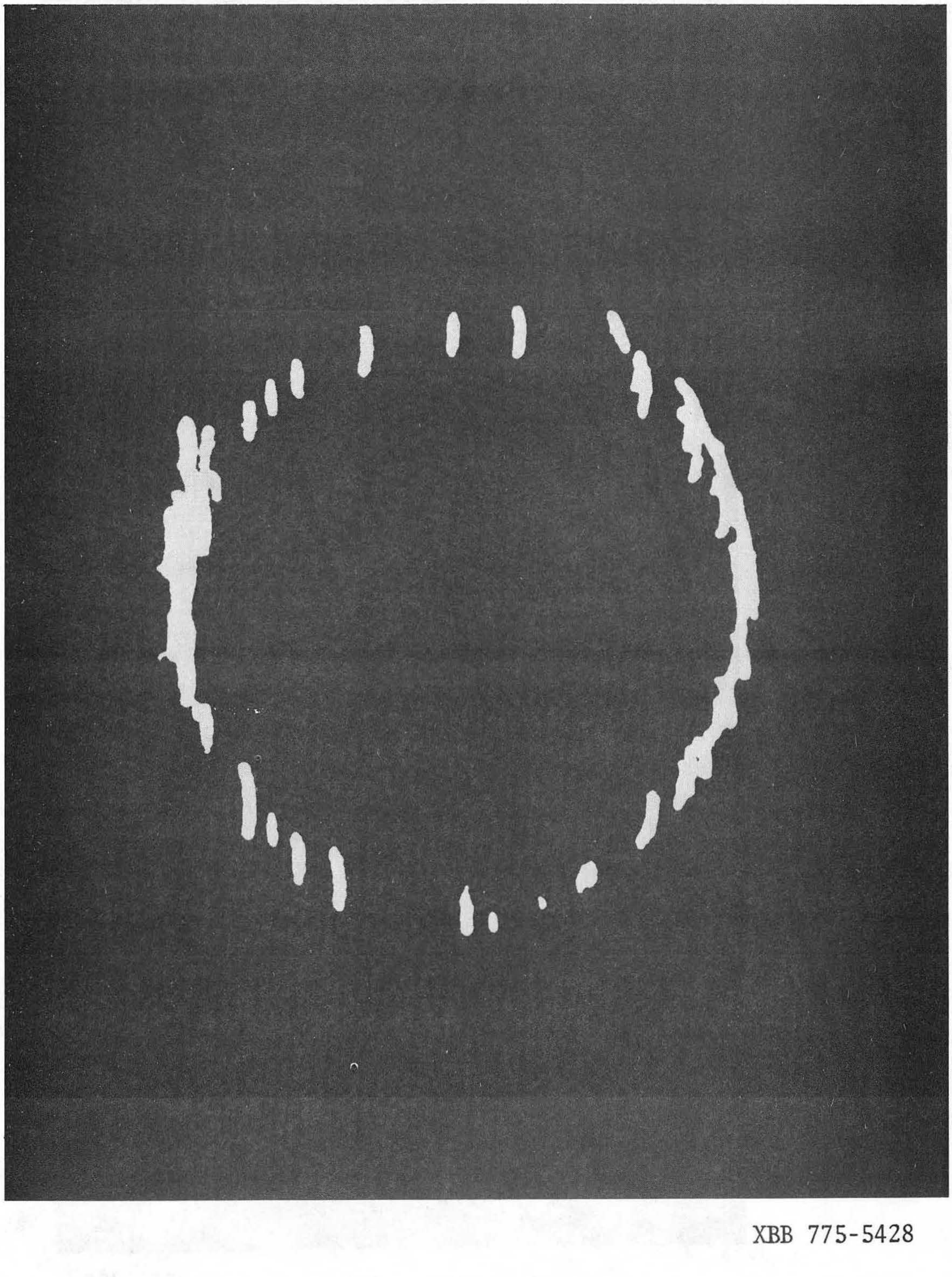

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Fig. 4b

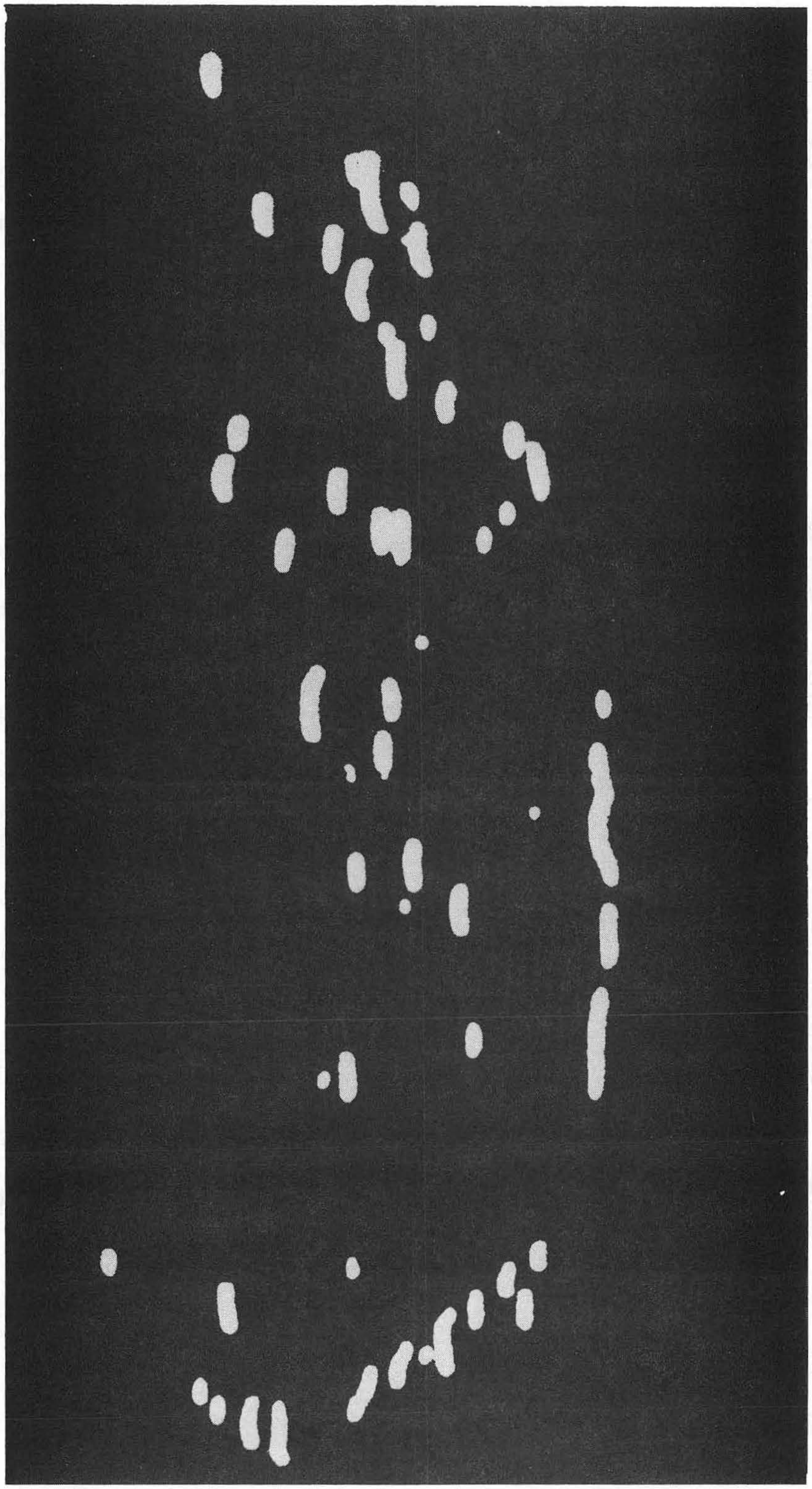

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Fig. 5a

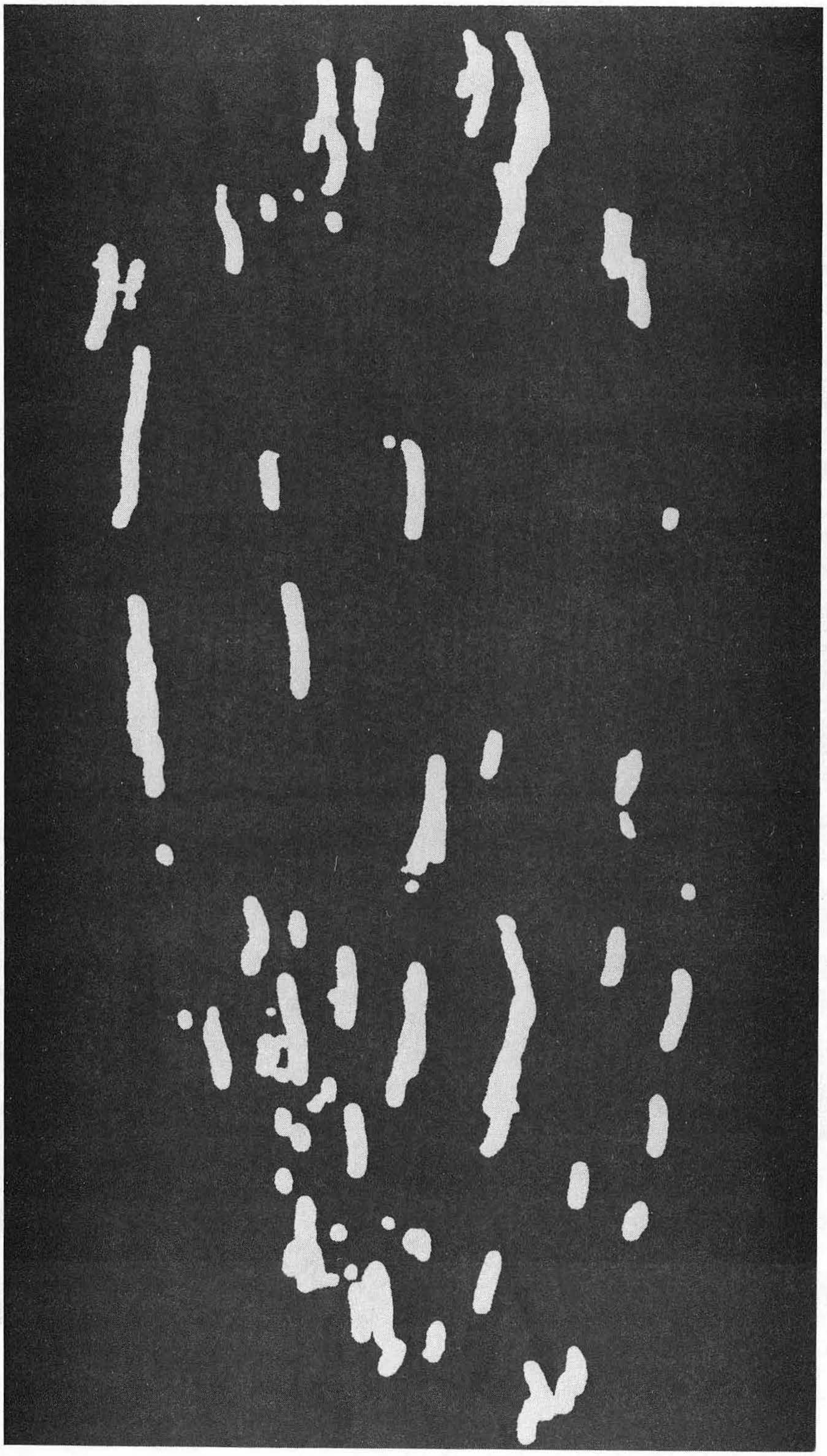

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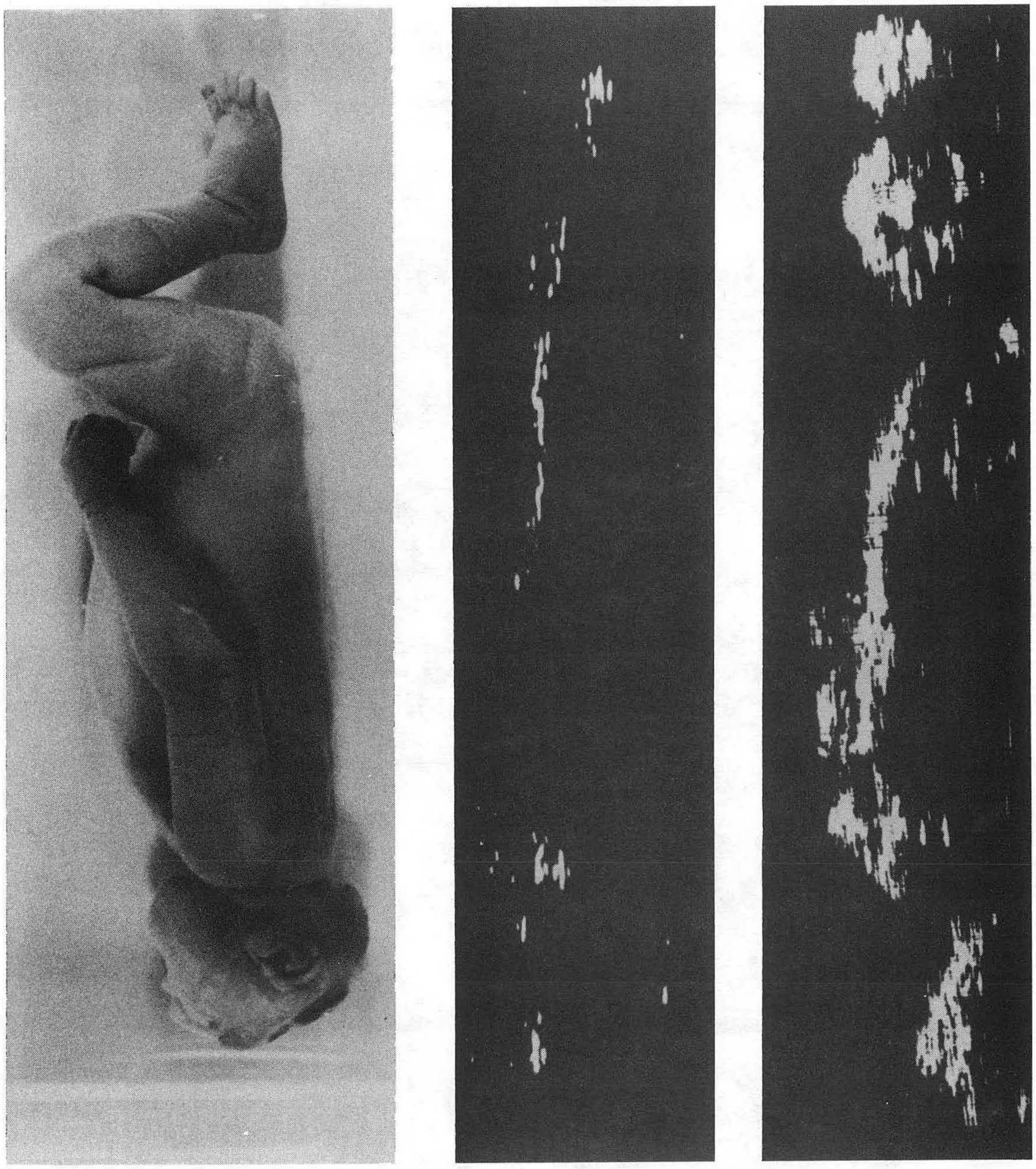
Fig. 5b



XBB 778-7787

Fig. 6

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