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AN INTERACTIVE DISPLAY TERMINAL FOR IMAGE MEASUREMENT USING AN X-RAY MICROBEAM SCAN SYSTEM*

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I. Introduction

Roentgenography is a valuable and widely used method for observing organs inside the human body. One of the serious problems to be solved in this method, however, is to eliminate undesirable biological effects which are inherently caused by x-ray irradiation. The development of a new technique capable of obtaining the necessary information with a minimum amount of x-ray irradiation is thus highly desirable.

A basic principle toward solving this problem is to use the following methods:

1) spatial restriction of the exposure area by selective irradiation to the necessary part of the body.

2) use of a highly sensitive detector of the transmitted x-ray.

These methods have been successfully adopted in the computer-controlled x-ray microbeam system developed in our institute [1), 2), 3), 4), 5)] for the selective scanning of x-ray microbeams on any part of a given object. Quantitative data on transmitted x-ray intensity patterns are stored in the computer. Also, an automatic tracking of a moving object, or of the contour of the object, is made with the selective irradiation on the necessary area of the object. Detailed descriptions of this system have been reported elsewhere. [3), 4)]

In the clinical use of this special x-ray measurement technique, however, a preliminary observation and selection of the specific location and method of measurement should first be made on an overall scanned image with low x-ray dose. The present paper describes an interactive display terminal system we developed for this purpose, and its applications to the observation of organ movements and to contour tracing.

2. Interactive Display Terminal System

A block diagram of the interactive display terminal system combined with the x-ray microbeam system is shown in Figure 1. The terminal diplay consists of a visual display unit and a control system.

In the visual display unit, a scan converter and a TV monitor are used for storing and displaying a scanned x-ray image. The scanning signal of the x-ray beam is also used as the scanning signal of the scan converter. This signal can be generated either by a separate "local sweep generator" (local mode) or by the computer (computer mode). In the former mode, the direct output of the x-ray detector is used as a write video signal of the scan converter, thus controlling the writing intensity of stored information. The image of arbitrary limited rectangular areas can

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be enlarged and displayed on the TV monitor by means of the scan converter's zoom gain control. The x-ray exposure can be controlled by varying the scanning speed.

In the computer mode, where a sample point can be randomly selected, the output of the detector is integrated for each of the sampled points and read into the computer through an A/D converter. The digitized data (8 bits) representing intensities of transmitted x-rays generate write video signals (4 bits) of the scan converter. Modification of the x-ray image, such as spatial smoothing and/or shift of overall brightness level, can also be performed in real time during x-ray beam scan. An additional circuit is provided for writing signals from the computer to the scan converter. Processed image and measured data stored in the computer, therefore, can also be memorized on the scan converter.

In order to specify the pertinent points for further measurement, a cross-mark is superposed on the x-ray image on the TV monitor. The cross-mark can be moved in x and y directions on the TV screen by operating a pair of manual digital selector switches. The coordinate values of the specified position are read into the computer. The accuracy of the coordinate values is approximately the same as that of the resolution of the TV monitor. Job selector switches are installed which control jobs and select parameters in the computer program. On the CRT monitor, computer-processed data, e. g., spatial and temporal patterns of the intensities of transmitted x-rays, are displayed in real time when necessary. These units have been assembled into an interactive control terminal for observation of x-ray images and for control of x-ray measurements.

The basic procedure of x-ray measurement using this interactive control terminal consists of the following steps:

1) preliminary observation of overall scanned x-ray image displayed on the TV monitor.

2) determination of necessary area on the display for further measurement.

3) selection of the mode of x-ray measurement.

4) automatic measurement and display of the result.

3. Display of Scanned X-ray Images

The pictures shown in Figure 2 are examples of scanned x-ray images displayed on the TV monitor by use of the local sweep generator In picture (a), which is an x-ray image of a model of the hand with a scanning time of 10 sec, the effect of quantum noise can be seen (100 Kv - 1.7 1.7 mA, 1 mm Aluminum filter). Figure 2 (b) shows an image obtained by scanning the model 10 times under the same x-ray condtion as in Figure 2 (a) and by superposing the data on the scan converter. The picture quality is seen to be improved by integration of x-ray intensity signals on the scan converter. Figure 2 (c) shows an enlarged x-ray image by scanning a limited area of 3.5 x 3.5 cm^2 in the central part of the hand model.

Figure 3 shows examples of coarse x-ray images of a lateral view of the human head scanned by the computer under various sampling conditions. In the computer-scanning, sampling points are specified by x- and y-coordinate values of 9 bits. Low-dosage x-ray image for preliminary observation can be obtained by rough scanning with decreased spatial density of sampling points. In this scanning, unexposed spaces between the sampling points on the scan converter are covered by using intensity data of neighboring sampling points. In Figure 3, the distances of sample points in (a), (b), and (c) are 0.9 mm, 1.5 mm, and 3 mm, and the total number of sample points are 170 x 170, 100 x 100, and 50 x 50 respectively. An x-ray image of the quality exhibited in (a) appears to be sufficient for an approximate observation of static tongue position during speech. The picture in (c), which is an extremely coarse image, is also useful for a preliminary observation assisting a special measurement. The x-ray beam used here was 150 KV - 2 mA with 0.6 mm Cu filter. The exposure time per sample point was 60 μsec. The total exposure time was 1.7 sec for (a), 0.6 sec for (b), and 0.15 sec for (c).

The exposure rate measured by means of TLD was 12 mR/min when an area of 10 cm^2 was scanned continuously by the x-ray beam mentioned above. Based on this value, the total x-ray dosages exposed for pictures (a), (b), and (c) were estimated as 15 μR, 5 μR, and 1 μR respectively.

Pictures (d) and (e) in Figure 3 show image displays after spatial smoothing of the picture shown in (a). In Figure 3 (f), the x-ray image in (a) is displayed after a shift in the level of brightness, thus improving the contrast in the regions of the palate and the nasal cavity. Flexibility of the scanning and image measuring process in the present system can match the scanned x-ray picture to the purpose of observation.

4. Measurement of Organ Movement

In the x-ray microbeam system, a quantitative measurement of the intensity of transmitted x-rays is performed by a scintillation counter. It is possible, thereby, to know the movements of organs by measuring the temporal variation of x-ray intensities on selected sample points. The cross-mark was used to specify these points on a coarse x-ray image displayed on the TV monitor. The computer read the coordinate values of the points to be exposed. The intensity pattern can be displayed on the CRT monitor in real time.

Figure 4 (a) is a coarse x-ray picture of Figure 3 (c) with a cross-mark specifying a point at the pharyngeal space. The measurement of transmitted x-ray intensity was made on 50 points along the horizontal line having the cross-mark at the center. The distance between each sample point was 1.2 mm. The measurement was repeated at a rate of 40 frames per second with an exposure time of 500 μsec per point. During the measurement, the subject pronounced a vowel sequence /a i a i a i u e o /. The temporal variations in the spatial intensity pattern, associated with tongue movement, are displayed in three-dimensional fashion in Figure 4 (b). The intensity curve for each frame is aligned along the time sequence of the measurements. In each intensity curve, from left to right, there is a decrease in intensity which corresponds to the "shadow" of the spinal vertebra and the posterior pharyngeal wall; this is then followed by an increase representing the pharyngeal cavity. The intensity then decreases again indicating the shadow of the tongue root. During the utterances of vowels /a/ and /o/ the intensity curves reveal that the pharyngeal space is narrowed in antero-posterior axis due to the backward shift of the tongue along the line of measurement. The pharyngeal space becomes wider for /i/ and /e/ due to the forward shift of the tongue. When the tongue moves forward, the intensity curve of the pharyngeal region shows a small dip which presumably corresponds to the shadow of the epiglottis. The five curves superposed on the x-ray image in Figure 4 (a) are, from bottom to top, the data for five consecutive frames during transition from /a/ to /i/. These curves provide information on the antero-posterior tongue movement as well as positions of the posterior pharyngeal wall and the surface of the tongue root.

Figure 5 shows another example of the dynamic observation applied to the cardiac wall. The coarse x-ray picture in (a) indicates an antero-posterior view of the left side of the human chest. The diaphragm shows its typical shadow at the bottom. Due to the heartbeat, occurring during the horizontal scan from bottom to top, the cardiac wall presents a figure which is similar to an x-ray kymogram.

The intensity pattern was obtained on 50 sampling points placed at 1.2 mm distance on a horizontal line centered at the cross-mark shown in the picture. The exposure time per point was 1 msec and the measurement was repeated at a rate of 20 frames/sec. A spatio-temporal intensity pattern is displayed in Figure 5 (b) in the same fashion as in Figure 4 (b). In each intensity curve, the low-intensity portion at the left and the high-intensity portion at the right indicate the heart and the lung respectively, showing a clear boundary between the two. A rhythmic shift of the boundary along the time course represents the pulsative movement of the cardiac wall. The five curves indicate temporal intensity variations at five selected sampling points. The amplitude and the wave form vary with the sampling points. The x-ray beam of 125 KV-1.7 mA with 1 mm Aluminum filter was used for the observation of the heart. The number of sampling points in the coarse x-ray picture was 100 x 100 (at spatial intervals of 1.5 mm), and the exposure time was 500 μsec per point.

5. Automatic Contour Tracing of Organs

In order to overcome the difficulty of fully automatic contour tracing, it is advisable first to give certain directions to the computer. The necessary information is obtained by preliminary observation of the x-ray image.

In the present procedure, a coarse x-ray picture is displayed on the TV monitor. The starting point and the direction of contour tracing are then specified on the picture with use of the cross-mark. A guide line for the initial scan which runs across the contour on the image is determined by the cross-mark. The cross-mark is also used for specifying direction of the contour tracing. The intensity pattern on the guide line is first estimated by the computer to find the point on the contour where the maximum gradient of the intensity variation is reached. Tracing of contour then starts in the specified direction. The algorithm of contour tracing has been reported elsewhere. [6), 7)]

Figure 6 shows a result of the contour tracing on the human articulatory organs. In (a), traced contour of the pharyngeal wall is superposed on a coarase x-ray image. The initial guide line was set horizontally in the hypopharynx across the contour of the tongue root. The figure indicates that the tracing proceeded upward along the posterior surface of the tongue to the lower edge of the mandibulla, then turned to the left, and finally proceeded downward along the posterior wall of the pharynx to the entrance of the esophagus. Figure 6 (b) indicates a traced contour of the surface of the tongue during pronunciation of the vowel /e/. The initial guide line was placed at the mesopharynx above the lower edge of the mandibulla. In Figures 6 (c) and (d), the traced contours in (a) and (b) are displayed separately. The initial guide lines are shown as short horizontal lines in the figures.

In these measurements, each point on the contour was determined by the data of 21 sample points with an exposure time of 500 μsec 150 KV-2 mA, 0.6 mm Cu filter). The step of tracing was approximately 0.6 mm. The x-ray exposure was limited to a narrow zone 5 mm wide along the contour. The total exposure dosage was estimated to be 500 μR.

Figure 7 shows another example of the contour tracing by this technique. The traced contour of the lesser curvature of the human stomach filled with Barium meal is superposed on a coarse x-ray image. The guide line in this case was placed horizontally at a level slightly below the opening of the esophagus into the stomach, the cardia.

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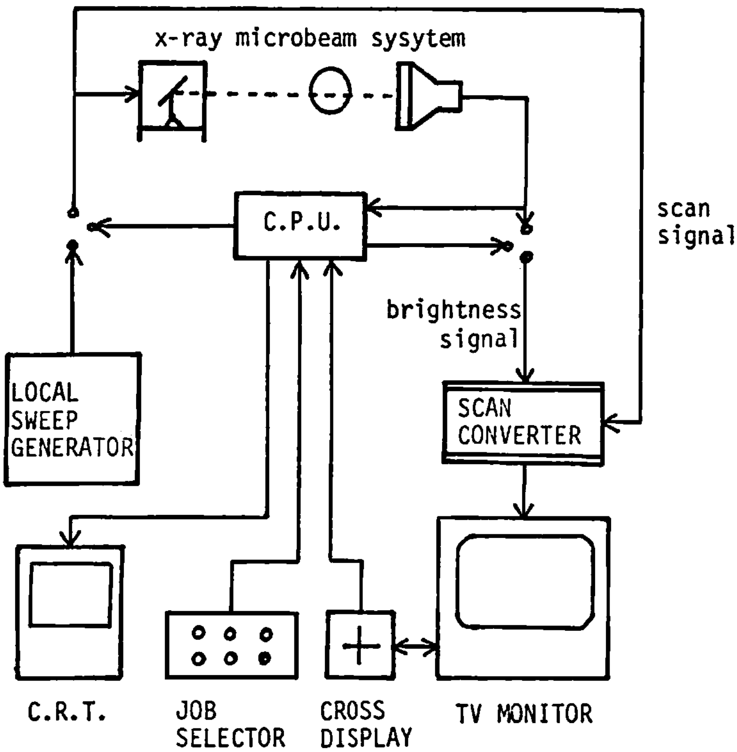
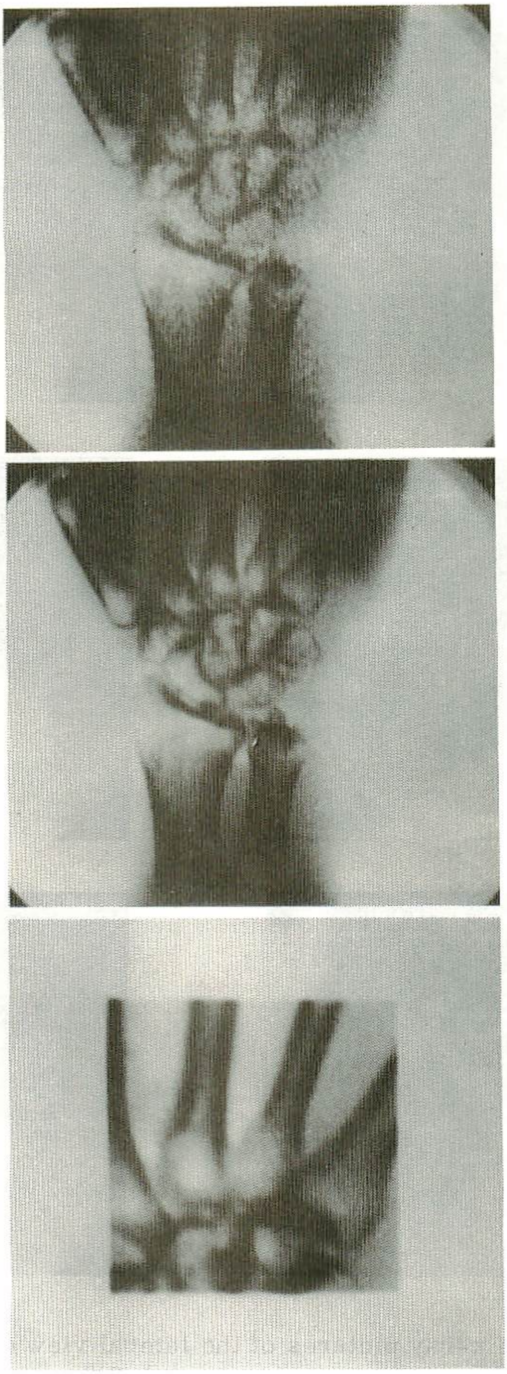


Fig. 1. Block diagram of the x-ray microbeam system connected to the interactive display terminal.



(a)

(b)

(c)

Fig. 2. Scanned x-ray pictures of a model of a hand by use of the scan converter tube and the TV monitor (local sweep). (a): A scan of 10 sec per frame; (b): Superposition of 10 repeated frames; (c): Enlarged image by scanning a part of the model.

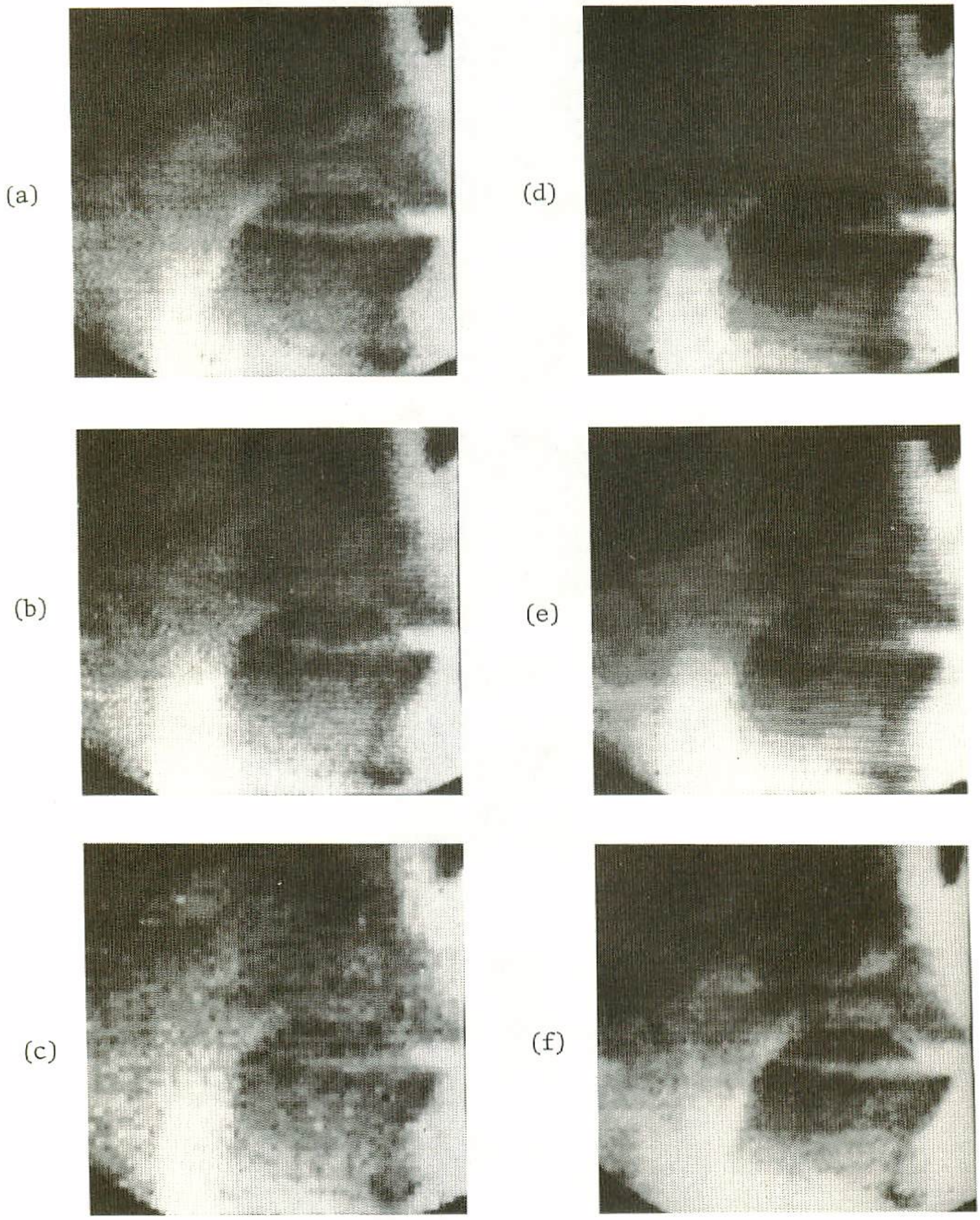
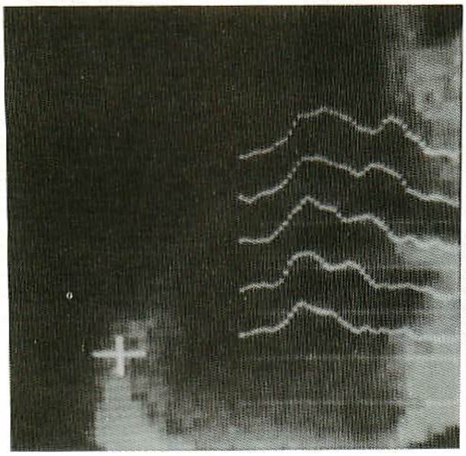
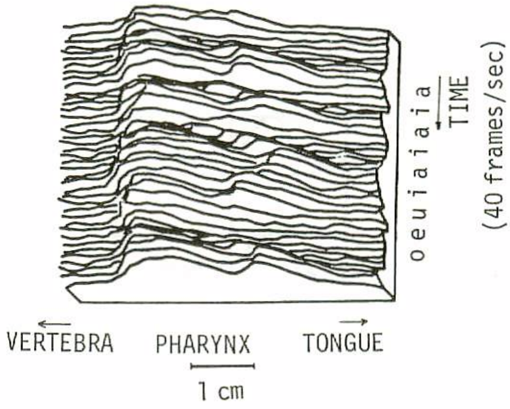


Fig. 3. Coarse x-ray pictures of the lateral view of the human head by computer-generated scan. (a): 0.9 mm step; (b): 1.5 mm step; (c): 3 mm step; (d) and (e): Pictures obtained from (a) by smoothing the spatial intensity pattern over 3(d) and 7(e) contiguous sample points in two dimensions; (f): Picture of (a) with a different level of the brightness window.



(a)



(b)

Fig. 4. Spatio-temporal variation of the transmitted x-ray intensity in the pharynx. (a): Coarse x-ray picture with a cross-mark specifying the location of measurement. (b): Three-dimensional display of the intensity variation associated with tongue movement.

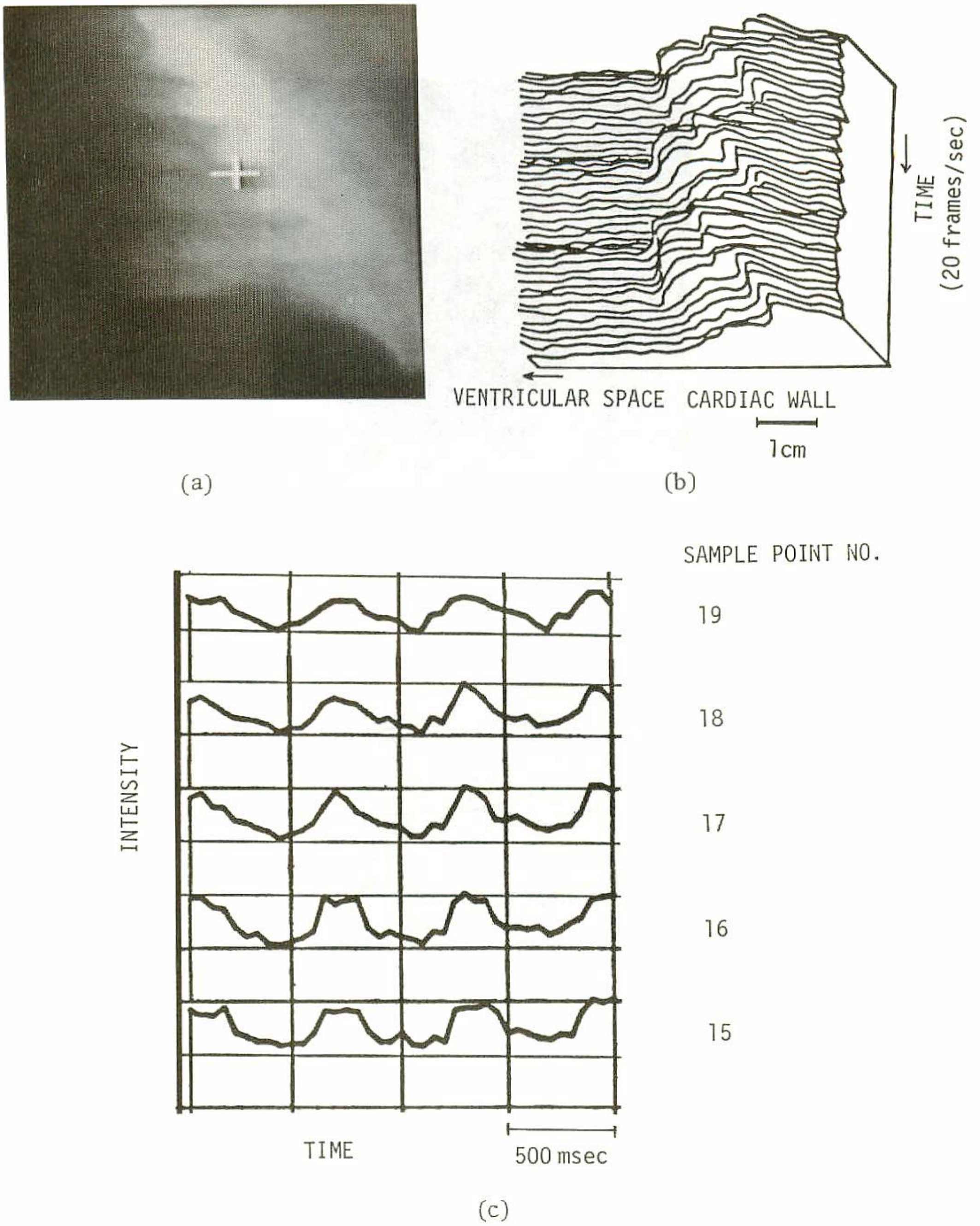


Fig. 5. Spatio-temporal variation of the transmitted x-ray intensity at the cardiac wall. (a): Coarse scan image of the heart; (b): Spatio-temporal variation due to the heartbeat; (c): Temporal variations of the x-ray intensity at selected sample points.

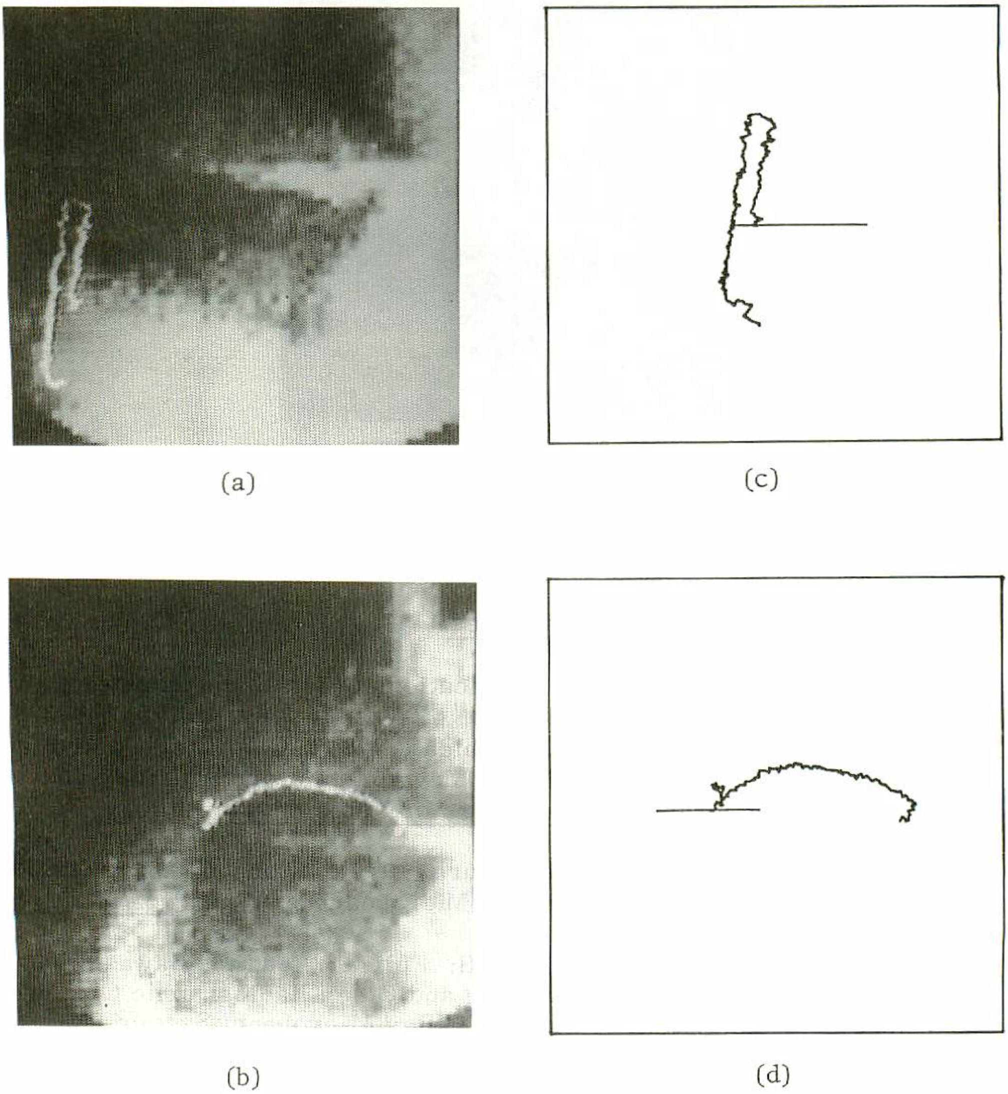


Fig. 6. Contour tracing of articulatory organs.
(a): Contour of the pharyngeal wall superposed on the coarse x-ray picture; (b): Contour of the tongue surface superposed on the coarse x-ray picture; (c) and (d): Trajectories of the contour tracings.

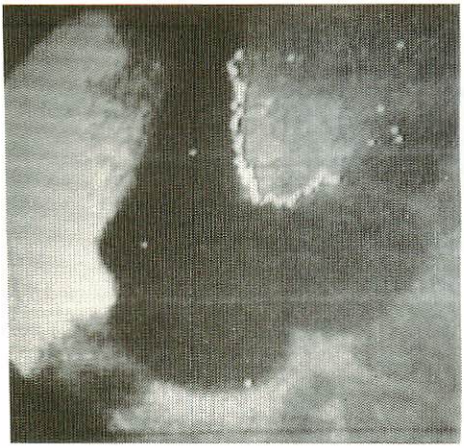


Fig. 7. Contour tracing of the lesser curvature of the stomach filled with Barium meal (P-A view).

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