A Proposal of a New Computed Tomograph for Direct Reconstruction of Arbitrary Cross-Section of the Body*

By

Y. Hayakawa and J. Egawa

Department of Radiology, Teikyo University School of Medicine, Tokyo 173, Japan

and

T.A. Iinuma

Division of Clinical Research, National Institute of Radiological Sciences, Chiba 280, Japan

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人体任意断面コンピュータ断層装置の提唱*

帝京大学医学部放射線医学教室

早川吉則　柄川　順

放射線医学総合研究所臨床研究部

飯沼　武

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人体の任意の断面の断層像を直接再構成しうる新型コンピュータ断層装置を提唱する．

提唱する装置はファンビーム状のX線，および複数の検出器によつて構成され，これらを，断層像を得ようとする面上で直線的に駆動する事により，ファンビームの角度によつて限定された角度内のX線吸収のプロフィルが得られる．このような限定された角度内でのプロフィルからの断層像の再構成の問題を数学的に検討した．また従来からあるコンピュータ断層装置を用いて提唱する装置を模した実験を行い，良好な結果を得た．提唱する装置の原理は放射型断層装置，陽電子消滅放射型断層装置，超音波断層装置にも応用できるものである．

Abstruct

A new computed tomograph is proposed, which enables direct reconstruction of arbitrary cross-sections of the body. The scanner consists of fan-beam X-rays and multiple detectors, that are scanned linearly on the plane to be reconstructed. Profiles are obtained in the limited range of angles. Reconstruction of the cross-section from such profiles are discussed mathematically. Simulation experiments using conventional computed

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tomograph have been carried out with favorable results. The principle is applicable to emission tomograph, positron annihilation tomograph and ultrasonic tomograph as well.

Introduction

Conventional X-ray-transmission computed tomograph (CT), in principle, deals with transverse sections of the body[1]. For organ systems, however, which lie parrallel to the long axis of the body such as kidney, spine, and major blood vessels, sagittal or frontal sections may be more important for diagnosis[2]. Conventional CT scanner displays sagittal or frontal sections by the rearrangement of serial transverse sections[3]. This method, however, has a disadvantage that the tissue outside the plane of interest must be exposed to the X-rays, resulting in a high volume-dose[2].

Another alternative is to obtain directly these sections by a conventional CT scanner of a large dimensions with scans more than the range of angles 180°. The scanner, however, seems to be inoperative for obtaining above sections due to the attenuation of X-rays through the body. X-rays must, in that case, penetrate, with sufficient intensity, the tissue of the sitting length (~90 cm), instead of the width of the hip (~35 cm). This means that the X-ray source of approximately 10 thousand times stronger, resulting much higher exposure to the patients, is necessary than that for transverse tomography, assuming that the X-rays of 120 KeV are employed[4]. In the present work, a scanner is proposed, which enables to section at any desired plane of the body with ordinary dose of exposure where only the tissue in the plane of interest is exposed. The scanner uses profiles within a limited range of angles instead of more than 180° used by the conventional scanner.

Principle of the Proposed Tomograph

The schematic set-up of the scanner is illustrated in Fig. 1. In the figure, fan-beam of X-rays of limited range of angle θ ($\theta<180°$) is transmitted through a patient and detected by multple detectors of the number of n. A X-ray source and the detector system are to be scanned linearly, resulting the number of n profiles within the limited range of angle θ from which the cross-section of the patient is to be reconstructed. Detectors need

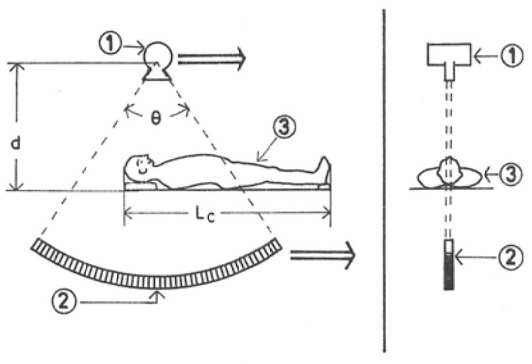


Fig. 1. Schematic set-up of the proposed X-ray transmission tomograph: 1. a fan-beam X-ray source, 2. X-ray detectors, 3. a patient, with other details such as X-ray collimators abbreveated; The tomograph is scanned linearly as indicated by large arrows. Change of the relative position between the patient and the scanner allows any desired cross-section to be displayed.

not be scanned in the case when sufficient length of the detector system is employed. The reconstruction of the cross-section from the profiles within the limited range of angles has been reported by Gordon et al.[5]. Here the number of profiles and number of the matrices are considered. We assume that a profile is taken for each increment of the linear movement $K\delta L$, where δL is the pixel length along the direction of a scan and k is a constant smaller than 1. Further following notations are defined; L_c the length of the arbitrary cross-section of a patient, m the number of pixel layers vertical to the direction of a scan, n the number of multiple detectors within the fan beam X-rays, d the distance between the X-ray source and the patient.

Although the X-ray tube and the detectors must be scanned more than a length of $L_c + 2\,d\tan\theta/2$ to obtain the full data of the cross-section, the effective length for data acquisition for a certain detector is L_c. Therefore, the number of equations obtained by a scan for each detector is

$$\frac{L_c}{k\delta L}\ . \tag{1}$$

As a consequence, the total number of equations obtained by one scan is

$$\frac{L_c}{k\delta L}\ n, \tag{2}$$

whereas the number of unknown parameters, i.e., the number of pixels is

$$\frac{L_c}{\delta L}\ m. \tag{3}$$

The condition that the number of linearly independent equations is equal or greater than the unknown parameters gives

$$m \leqq \frac{n}{k}\ . \tag{4}$$

Therefore the number of pixel layers perpendicular to the direction of a scan should be equal or smaller than n/k. For example, when the pixel size of 2 mm×2 mm is required in the reconstruction of the body of width 40 cm, we should employ sampling distance of 2 mm and the number of detectors of 200 that lie within the angle θ of the fan-beam X-rays in the case of k=1.

Considerations on noises, however, may require smaller sampling distance and more detectors.

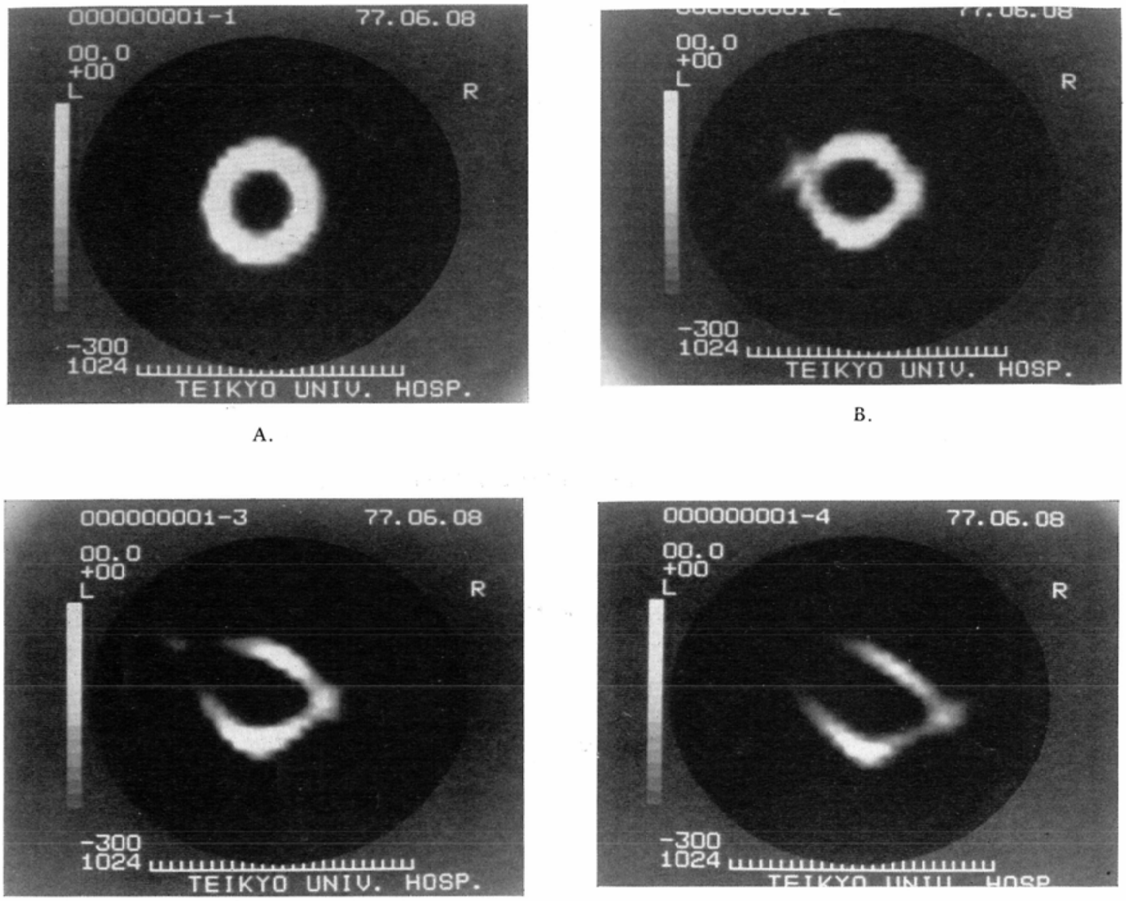
Experiment

The principle of the proposed scanner is checked by a conventional CT scanner HITACHI CT-W, which is of the type of the 3rd generation and uses filtered back-projection method for reconstruction.

A phantom used in the experiment was a tube made of polyvinylchloride with the outer diameter of 23 mm and inner one of 18 mm. The tube was inserted into the scan field of view in fixed periods during that the X-ray tube and detectors rotated by a certain angle. As a consequence, the profiles were obtained within the limited range of angles.

The results are shown in Fig. 2, showing in an enlarged scale, the reconstructed images of the phantom from scans taken over 212°, 80°, 55° and 33°.

Although the the reconstructed image is best for 212°, that for 80° is tolerable and will be improved by the use of more suitable reconstruction algorithms such as iterative reconstruction[5].



A.　　B.　　C.　　D.

Fig. 2. Experimentally reconstructed images from profiles of the limited range of angles using HITACHI CT-W scanner: the limited range of angles; A. 212°, B. 80°, C. 55°, D. 33°.

Discussion

The principle of the proposed tomograph is applicable to other kinds of computed tomograph such as emission tomograph, positron emission tomograph and ultrasonic tomograph[6]. The scanner for emission tomography is illustrated in Fig. 3. In the figure, collimated γ-detectors, whose inclinations are different with each other, are scanned linearly.

The scanner for positron emission tomography is similar to that for emission tomography except, in the former, coincidence counting method is used instead of the collimator system in order to determine the direction of the annihilation radiations.

Conclusion

A new computed tomograph is proposed which enables the direct reconstruction of arbitrary cross-section of the body.

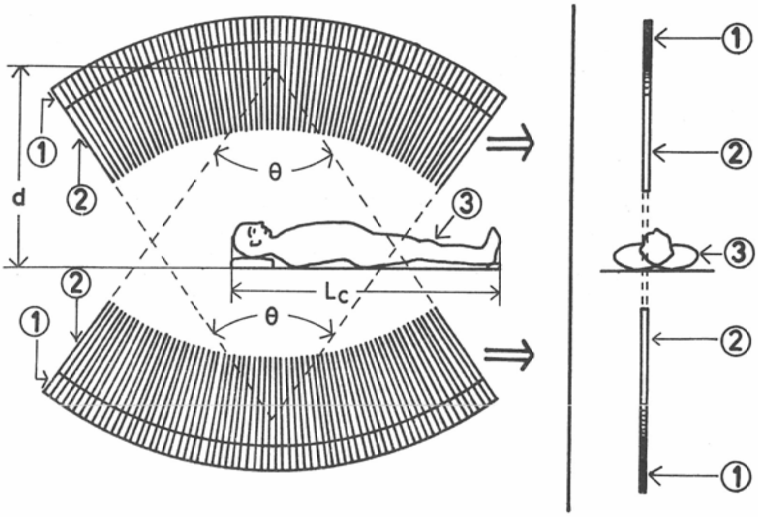


Fig. 3. Schematic set-up of the proposed emission tomograph: 1. γ-ray detectors, 2. collimators, 3. a patients, with other details abbreviated; The tomograph is scanned linearly as indicated by large arrows. Use of multiple detector couples instead of one would allow many cross-sections displayed simultaneously

The scanner can be applied to the fields other than medical one, e.g., a belt-conveyer system which is equipped with this kind of tomographs will display cross-sections of the products serially. Reconstruction algolisms for the proposed tomograph are under developement at our laboratories.

References

1) Hounsfield, G.N.: Computerized transverse axial scanning (tomography): Part 1. Description of system. Brit. J. Radiol., 46: 1016-1022, 1973
2) Gordon, R.: Dose reduction in computerized tomography. Invest. Radiol., 11: 508-517, 1976
3) Brooks, R.A. and Di Chiro, G.: Principles of computer assisted tomography (CAT) in radiographic and radioisotopic imaging. Phys. Med. Biol., 21: 689-732, 1976
4) Phelps, M.E., Hoffman, E.J. and Ter-Pogossian, M.M.: Attenuation coefficients of various body tissues, fluids, and lesions at photon energies of 18 to 136 KeV. Radiology, 117: 573-583, 1975
5) Gordon, R., Bender, R. and Herman, G.T.: Algebraic reconstruction techniques (ART) for three-dimensional electron microscopy and X-ray photography. J. Theor. Biol., 29: 471-481, 1970
6) Greenleaf, J.F., Johnson, S.A., Samayoa, W.F. and Duck, F.A.: Algebraic reconstruction of spatial distributions of acoustic velocities in tissue from their time-of-flight profiles. Acoustic Holography, 6: 71-90, 1975