FROM KODAK AB, THE DEPARTMENT OF DIAGNOSTIC RADIOLOGY (DIRECTOR: PROF. B. NORDENSTRÖM), KAROLINSKA SJUKHUSET, AND THE DEPARTMENT OF CLINICAL RADIOPHYSICS (DIRECTOR: PROF. R. WALSTAM), THE NATIONAL INSTITUTE OF RADIATION PROTECTION, STOCKHOLM, SWEDEN.

DIRECT BEAM CONTROL IN RADIOTHERAPY WITH HIGH ENERGY PHOTONS

by

L. JEVBRATT, C. LAGERGREN and B. SARBY

Controls performed directly with a therapy beam instead of a separate roentgen simulator eliminate uncertainties in the repositioning of the patient between the simulator and the therapy unit. The position of the beam in relation to the anatomic structures will also be ascertained more precisely. Moreover, shielding blocks for radiosensitive organs, such as the spinal cord, kidneys and eyes will be placed more accurately and the margins to these organs reduced. A method of direct beam control is particulary valuable when high-energy roentgen radiation from linear accelerators and betatrons is used, since the well defined beam of the units will be exploited for precise tumor treatment.

The difficulty of employing the therapy beam for roentgenography at high photon energies is due to the small difference in the mass absorption coefficients of bone and soft tissues. The radiation contrast in the traversing beam will be due chiefly to variations in tissue density in the irradiated volume implying a consequent reduction in the image contrast in the roentgenogram. In spite of this

Submitted for publication 30 June 1970.

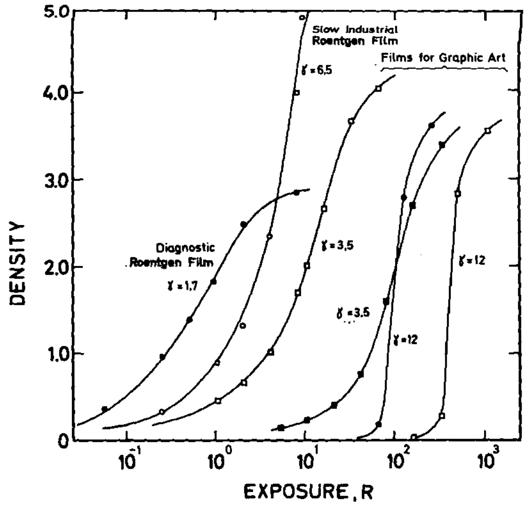


Fig. 1. Characteristic curves for various types of film irradiated with 6 MV roentgen radiation. Left to right at exposure axis: Fuiji Medical Diagnostic Film, Kodak Microtex, Gevaert N 51, Kodak Phototypesetting, Kodalith Royal Ortho and Kodalith Ortho Type 3.

difficulty it has still been possible to utilize the direct therapy beam by applying metal indicators or gas as contrast media to produce interpretable control films. This technique has been applied in earlier investigations either with photographic film (LINDELL & WALSTAM 1956, FRISCHBIER & KUTTIG 1960, PERRYMAN et coll. 1960, TASKINEN & VÄHÄTALO 1968) or with special image intensifier systems (MALVÉN et coll. 1968). As early as 1945 MERMAGEN described a 1 MV human chest roentgenogram and later TUDDENHAM et coll. (1953) reported that supervoltage roentgenographic technique would increase the diagnostic value of chest roentgenograms.

The recent introduction of a new cobalt-60 unit (Siemens Gammatron 3), a 6 MeV linear accelerator (Varian) and a 42 MeV betatron (Siemens) at Radiumhemmet has made direct and rapid beam control all the more desirable. The results of trials of the above methods were often most difficult to interpret at the high photon energies from the accelerators. The present investigation was accordingly undertaken with a view to increasing the contrast in the beam control images by finding the optimal film, exposure conditions and processing parameters.

Method. A number of diagnostic films, low-sensitivity industrial films and graphic films, were irradiated for a number of exposures with 6 MV roentgen radiation in order to compare their properties. The processing procedure for the respective films was adjusted individually in accordance with the manufacturers' instructions for maximum contrast. The slope of the characteristic curve

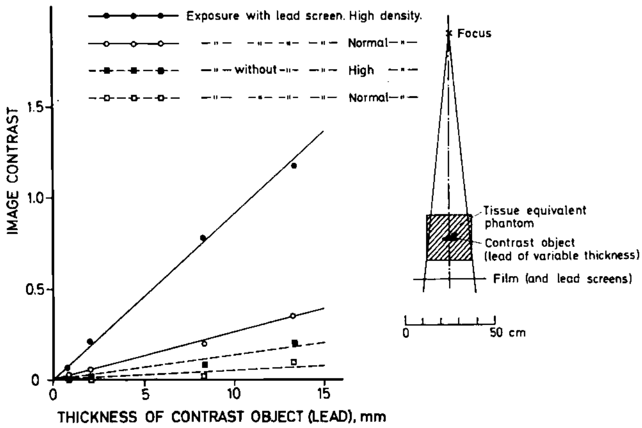


Fig. 2. Image contrast at high (3.5 to 4.0) and normal density (1.0 to 1.5) on Kodak Microtex film in recording of metal absorbers of different thicknesses in a tissue equivalent phantom. The image contrast is determined by the differences in density of the film beside and behind the contrast object. The exposures were performed with 6 MV roentgen radiation with the films either between lead screens or in a paper envelope.

increased at high densities for the industrial film (Fig. 1). The slope for the other films decreased at high densities. The maximum film contrast, γ, represented by the maximum slope of the curves, was 1.7 for the diagnostic film and 6.5 for the industrial film, while for graphic film it ranged from 3.5 to 12. The most suitable film, judged from contrast properties, was the low-sensitivity industrial film with $\gamma = 6.5$ or graphic film with $\gamma = 12$. The industrial film Kodak Microtex was chosen for the subsequent work primarily because of its more suitable exposure range (latitude) and sensitivity compared to the graphic film as regards the magnitude of the daily treatment doses. Industrial film can also be processed automatically in the developing machine (Kodak Versamat 317) for diagnostic films while graphic film must be developed manually.

The films in Fig. 1 were placed during irradiation between polished lead screens, 2 mm thick, a value found to be suitable at all the relevant beam energies. The purpose of these is to produce Compton electrons and characteristic radiation to blacken the film and to absorb oblique secondary electrons and scattered photons from the patient. The value of the lead screens was examined by an experiment depicted schematically in Fig. 2. Pieces of metal of different thickness were placed in the middle of a homogeneous phantom, which was irradiated with 6 MV roentgen radiation. The recording on the Kodak Microtex

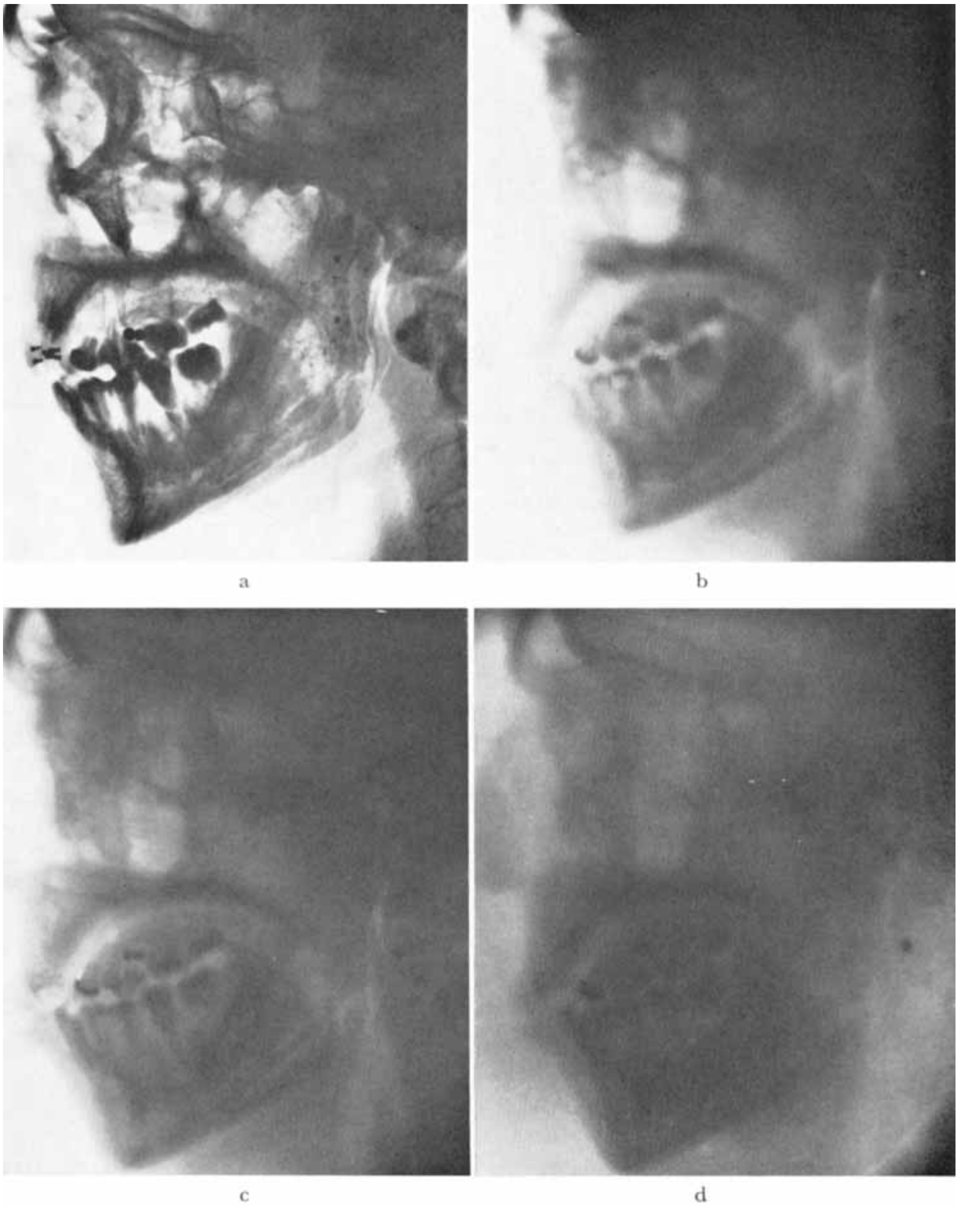
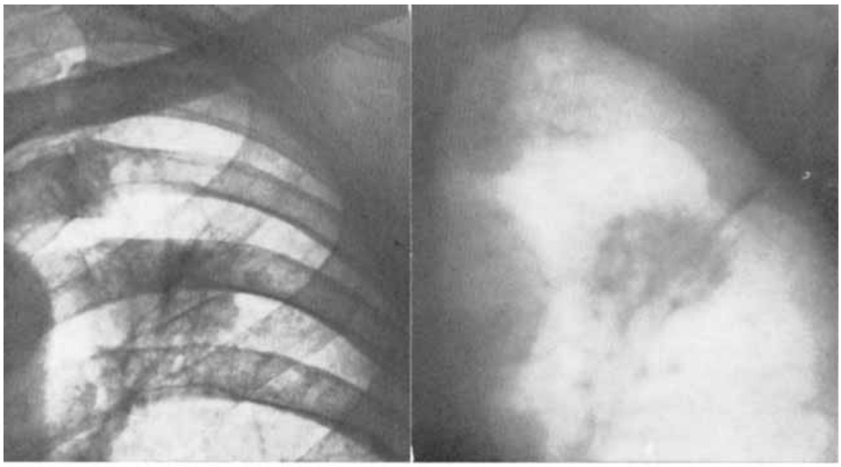
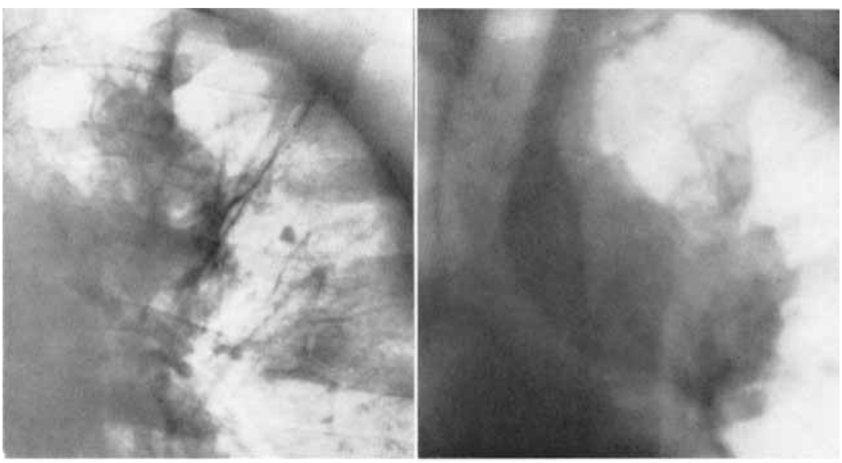


Fig. 3. Skull phantom exposed with a) simulator (65 kV), b) gamma radiation from a cobalt unit, c) 6 MV roentgen radiation from a linear accelerator and d) 42 MV roentgen radiation from a betatron. The film exposed with ^{60}Co radiation (b) has the best contrast of those obtained with the therapy units, but the large diameter of the source (2 cm) produces considerable geometric blur. Owing to the higher radiation energies the contrast is slightly poorer for the 6 and 42 MV roentgen (c) and (d) than for the ^{60}Co radiation (b), but the definition is better because of the smaller focus (2 mm).



a b

Fig. 4. Carcinoma of the lung. a) Diagnostic roentgenogram. b) Beam control film exposed with the linear accelerator for 3 sec. The extent of the tumour is clearly evident in the roentgenogram exposed in the therapy beam.

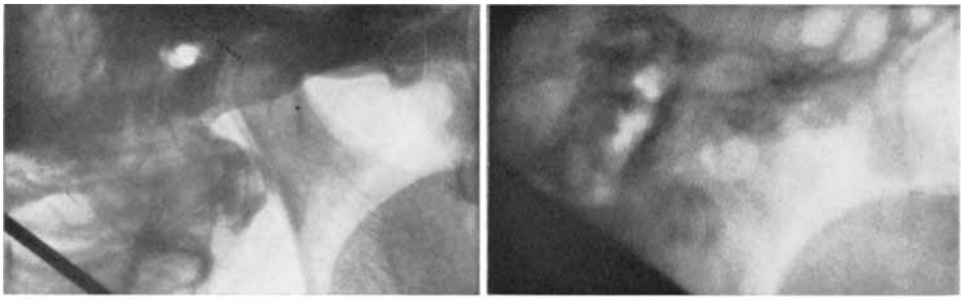


a b

Fig. 5. Carcinoma of the lung. a) Diagnostic roentgenogram. b) Beam control film exposed with the linear accelerator for 3 sec.

film was considerably greater for the films exposed in contact with the lead screens than for those enclosed in paper envelopes.

The best image quality is obtained by a heavy exposure because the contrast of industrial film increases with density (Figs 1 and 2). By producing contact



a b

Fig. 6. Nasopharyngeal carcinoma. a) Control of a lateral beam with the simulator. b) Corresponding control with linear accelerator beam. Poor agreement between the beams of the accelerator and the simulator, even though the films were taken in close succession.

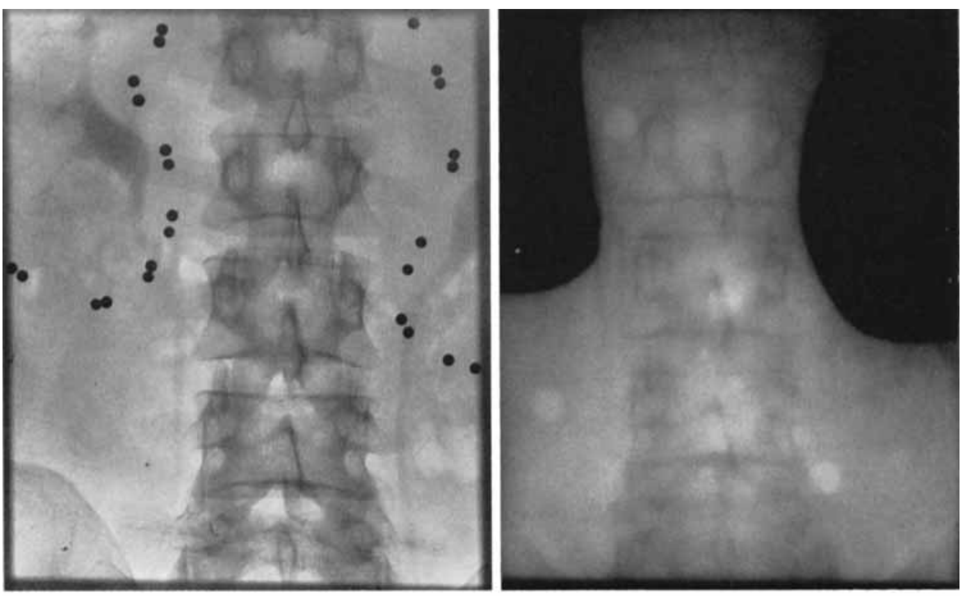
copies of the roentgenogram on duplicate film, however, an image with normal density but still the same contrast can readily be obtained. A further increase in the contrast of the original image may be produced if required by means of contact copies on a graphic film. For routine work, however, it suffices to examine the heavily exposed roentgenogram under a high-intensity illuminator.

A tissue equivalent skull phantom was exposed with gamma radiation from the cobalt unit, 6 MV roentgen radiation from the linear accelerator and 42 MV roentgen radiation from the betatron to examine the recording of the various structures on the low-sensitivity industrial film at the relevant radiation energies. The films, together with the corresponding roentgenogram obtained with the simulator (65 kV), are presented in Fig. 3. The film exposed with the cobalt unit had the best contrast of the roentgenograms obtained with the therapy units, but due to the large source diameter (2 cm) it was geometrically blurred. The roentgenograms exposed with the linear accelerator and betatron had slightly poorer contrast because of the higher radiation energies, but were sharper because of the smaller foci (about 2 mm). In all these cases, however, the film always registers a variation in tissue absorption large enough to permit anatomic details to be examined without the aid of indicators.

Discussion

Taskinen & Vähätalo (1968) have pointed out that it is desirable to expose the beam control film throughout the whole treatment time. At high energy photon radiation, when the differences in mass absorption coefficient of different tissues are small, this point of view is however difficult to fulfil if roentgenograms of sufficient high image contrast are required, depending on the contrast and the

Fig. 7. Chordoma of the atlas and epistropheus with destruction (arrows). A film exposed with the betatron 42 MV roentgen radiation for control of a lateral beam. The anatomic details appear clearly enough to define the position of the beam.



a b

Fig. 8. Sternberg's disease. a) Simulator film in which the contour of the kidneys has been marked after injection of contrast medium. b) Beam control obtained with the linear accelerator with the kidney protecting block in correct position. The vertebrae are clearly enough reproduced to define the position of the therapy beam.

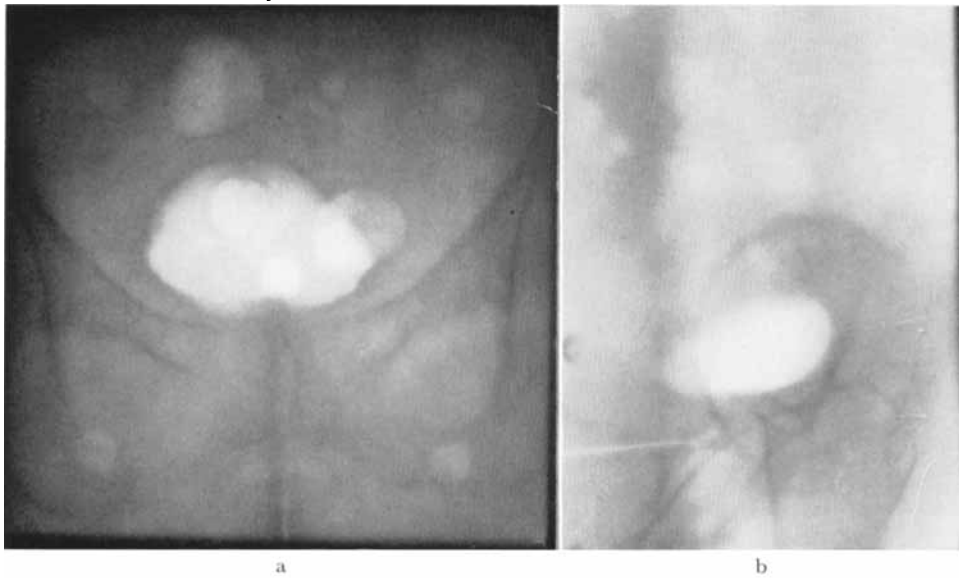


Fig. 9. Carcinoma of urinary bladder. Direct beam control films exposed with the linear accelerator with about 30 ml carbon dioxide in the bladder. a) Control of a beam from behind. b) Control of a wedge filter beam at 60° angle of incidence to the sagittal plane.

latitude of a film being reciprocal quantities. Moreover it can be an advantage as in ordinary diagnostic examinations, to employ short exposure times, i.e. obtained with films of high sensitivity in order to counteract blur due to movement. A suitable density of the industrial film is obtained by a dose of 5 to 20 rad to the patient; this requires an irradiation time of 1 to 5 seconds, which is short enough for the patient to be able to hold his breath. This is particularly important at beam controls of malignant processes located in the lungs and abdominal organs (Figs 4 and 5). It is also advisable to use short exposures when there are difficulties in reproducing the position of the patient in the therapy beam from one treatment to another, e.g. in the treatment of cranial tumours. A rapid check of the beam may then be carried out and any adjustment required made before the therapeutic irradiation is started. This kind of beam control requires however that the position of the patient on the treatment table is fixed throughout the whole treatment time.

The advantage of direct beam control is illustrated in Fig. 6, which represents control of a lateral beam for the treatment of nasopharyngeal carcinoma. A surprisingly poor coincidence appears between the beams of the therapy unit and the roentgen simulator, in spite of the fact that the films were taken in close succession. The deviation is partly due more to lower mechanical accuracy of the simulator (JUNG et coll. 1968) than to the linear accelerator. The correspondence between the roentgen beam and the light beam localizing system is also lower for the simulator. Of less significance is the difficulty in reproducing the patient position from one exposure to another, in particular when the patient is fixed by a plastic mould.

The great difference in the density of air and tissue enhances the demonstration of pathologic changes in the lungs and mediastinum extremely well in roentgenograms exposed with high energy photons. The better impression of the extent of the tumour in films obtained with the linear accelerator than with diagnostic radiation is evident from Figs 4 and 5. Irradiations with beams that have traversed bony structures record these clearly; they may therefore serve as reference points for estimating the position of the therapy beam (Figs 7 and 8). The position of the shielding block for radiosensitive organs may also be accurately controlled.

The difference in absorption between gas and tissue in direct beam control of tumours of the urinary bladder may be exploited by injecting a suitable amount of carbon dioxide (about 30 ml) into the bladder just before the exposure is made (Fig. 9). One advantage of carbon dioxide over air is that air embolism is avoided (BARTLEY & HELANDER 1960). The risk of infection may be minimized by injection of the gas through a millipore filter (Swinnex).

Direct beam controls have been performed routinely for the last two years in the case of treatment with the cobalt unit, the linear accelerator and the betatron. As is evident from the above examples, the method has proved very valuable for different techniques of tumour irradiation.

SUMMARY

It is an advantage to be able to perform set-up controls directly with the therapy beam in the precise radiotherapy of deep-lying tumours with a cobalt unit, linear accelerator or betatron. A special photographic method has been evolved by means of which this is possible. Examples are given of radiotherapy techniques in which the method has proved particularly valuable; it is very suitable for routine beam controls.

ZUSAMMENFASSUNG

Es ist ein Vorteil, direkt Kontrollbilder mit dem Therapiestrahl bei der genauen Radiotherapie von tiefliegenden Tumoren mit einer Cobolt-Einheit, einem lineären Accelerator oder einem Betatron durchführen zu können. Es wurde eine spezielle photograpische Methode entwickelt, mit deren Hilfe dieses möglich ist. Es werden Beispiele für radiotherapeutische Techniken gegeben, bei denen sich diese Methode als besonders wertvoll erwiesen hat; diese ist auch für routinemässige Strahlengangkontrollen sehr brauchbar.

RÉSUMÉ

Il est avantageux de pouvoir contrôler directement la mise en place du sujet par le faisceau de radiothérapie dans la radiothérapie précise de tumeurs situées en profondeur avec une unité de colbalt-thérapie, un accélérateur linéaire ou un bétatron. Les auteurs ont mis au point une méthode photographique spéciale qui permet ce contrôle de mise en place. Ils donnent des exemples de techniques radiothérapiques dans lesquelles cette méthode s'est montré particulièrement utile. Elle convient très bien pour le contrôle systématique des faisceaux d'irradiation.

REFERENCES

BARTLEY O. and HELANDER C. G.: Double-contrast cystography in tumours of the urinary bladder. Acta radiol. 54 (1960), 161.

FRISCHBIER H.-J. und KUTTIG H.: Zur Technik der direkten Feldkontrollaufnahme mit der Telekobalttherapieeinheit. Strahlentherapie 113 (1960), 610.

JUNG B., LARSSON B., ROSENGREN B. et coll.: Roentgen stand for field positioning in high-energy radiotherapy. Acta radiol. Ther. Phys. Biol. 7 (1968), 282.

LINDELL B. and WALSTAM R.: A new telegamma apparatus. Acta radiol. 45 (1956), 235.

MALVÉN R., ROSENGREN B. and WALLMAN H.: Field control in roentgen therapy with a 5 MeV linear accelerator by means of television. Acta radiol. Ther. Phys. Biol. 7 (1968), 462.

MERMAGEN H.: Million-volt chest radiograph. Radiogr. clin Photogr. 21 (1945), 68.

PERRYMAN C. R., MCALLISTER J. D. and BURWELL J. A.: Cobalt 60 radiography. Amer. J. Roentgenol. 83 (1960), 525.

TASKINEN P. J. und VÄHÄTALO S.: Feldkontrolle mit Kobalt-60-gammastrahlen während der gesamten Bestrahlungszeit. Strahlentherapie 136 (1968), 557.

TUDDENHAM W. J., HALE J. and PENDERGRASS E. P.: Supervoltage diagnostic roentgenography. Amer. J. Roentgenol. 70 (1953), 759.