PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
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# Diagnostic Visualization [and Discussion]

B. J. Shepstone, A. Nemet and P. N. T. Wells

*Phil. Trans. R. Soc. Lond. A* 1979 **292**, 177-185
doi: 10.1098/rsta.1979.0052

*Phil. Trans. R. Soc. Lond.* A. **292**, 177–185 (1979)
*Printed in Great Britain*



# Diagnostic visualization

By B. J. Shepstone
*Department of Nuclear Medicine, Groote Schuur Hospital and the University of Cape Town, Observatory, Cape, R.S.A.* 7925

[Plates 1–4]

The concept of total diagnostic visualization is based on the presumption that on the whole no single radiological investigation is self-sufficient and that it should be considered in relation to all other available diagnostic modalities. Although nuclear medicine techniques are expanding rapidly, especially for functional investigations, and have the advantage of non-invasiveness and sensitivity (which are ideal requisites for population screening), they remain relatively non-specific. This paper attempts to show how improved specificity may be effected by means of cross-modality techniques, and this is discussed in relation to the detection of cerebral abscess, focal hepatic defects, pulmonary emboli and deep-vein thromboses. An example of how the technique can be used in an engineering situation, namely to discover defects in concrete, is also considered and related to the philosophy outlined in the medical situation.

'Prove all things; hold fast that which is good.' (1 Thessalonians 5:21)

## Introduction

Diagnostic visualization may be defined as the use of all available modalities such as conventional röntgenology, contrast studies, radionuclide procedures, ultrasonographic studies, computed tomography, thermography, holography, etc., in the assessment of a problem in medicine, engineering or any other discipline where structural and functional abnormalities not visible to the naked eye have to be elucidated by means of non-destructive methods.

As a working idea in radiology this concept of diagnostic visualization is certainly not new, but it nevertheless has some positive advantages which are worth mentioning.

By and large, ultrasound and computed tomography demonstrate anatomical structures, while nuclear medicine emphasizes the physiological or functional approach to the study of organs. Holography, although it has some limited application in opthalmology, still has to realize its full potential in medicine. Thermography is interesting, but so far still limited in its applications.

The purpose of any new diagnostic technique in medicine must be evaluated in terms of information content, patient convenience, cost and time of execution. Only if these comparisons are favourable will the new technique replace the old and New Testament advice quoted above come into its own. However, in this paper I hope to show that while in each of the four medical applications and in the single engineering usage to be discussed one of the techniques does emerge as the most favourable, this concept of cross-modality investigation will become manifest as a realistic approach.

To illustrate this point, the detection of focal hepatic defects, cerebral abscesses, deep-vein thromboses and pulmonary emboli will be discussed as medical examples. A situation in which the approach can be used in civil engineering to detect defects in concrete will also receive attention. My only reason for selecting these particular examples is, quite simply, that they explain my thesis and that I am familiar with them.

## Focal hepatic lesions

Focal hepatic abnormalities may be due to a variety of causes, including inflammatory–infectious lesions, tumours, post-traumatic changes, vascular causes, cysts, fibrosis–cirrhosis, infiltrations, bile ducts dilated owing to obstruction, focal nodular hyperplasia and following therapeutic irradiation. The diagnostic techniques available for liver disease, besides the obvious clinical, biochemical and immunological approaches, include X-ray techniques, radionuclide imaging, computed tomography and ultrasound.

An example of how correlative methods may be used is illustrated in figure 1, plate 1, which is a case of an amoebic abscess which was scarcely visible on rectilinear scanning. The gamma camera was somewhat more revealing and ultrasound finally delineated the lesion.

Mention should also be made of double-radionuclide techniques in the diagnosis of focal hepatic disease, particularly the use of selenium-75 selenomethionine and gallium-67 citrate. The former is used as an aid in the differential diagnosis of hepatoma, when the irregular cold area caused by the lesion on the colloid scan is often seen to be 'filled in' on repeat scintigraphy with selenium-75 selenomethionine. One should also recall the role of gallium-67 citrate in delineating foci of infection and in particular Geslien, Thrall & Johnson (1974) have shown that in cases of hepatic amoebic abscess, gallium-67 citrate accumulates in the periphery of the abscess cavity and coincides with the region of hyperaemia seen histologically and arteriographically. It is therefore suggested that scanning with this agent is in fact more accurate in assessing the size and resolution of acute hepatic amoebic abscess than the colloid scan. A similar hypothesis was advanced by Cuarón, Gordon, Munoz & Landa (1973), who used flow studies in the delineation of focal hepatic defects.

From the type of example cited above it will be obvious that a single radiological investigation is often not self-sufficient and that it should be considered in relation to all other available diagnostic modalities. This sentiment has been expressed by many workers in the past. For example, Rossi & Gould (1970) have stated that 'the two techniques of arteriography and scanning are complementary to each other, but that the scan is an excellent method of screening'. In their study of 105 cases investigated in this way they obtained a positive diagnosis by combined study in 92 % of cases. Positive diagnoses by radionuclide scan and by arteriogram were 81 and 88 % respectively.

Similarly, Lee, Wilson, Waxman & Siemsen (1974) have stated that sonography and conventional scintigraphy 'give complementary information and should be used concurrently as "first line" differential diagnostic tools'. They have obtained a 98 % pickup rate for focal lesions by using radionuclides, 89 % by using ultrasound, but 100 % by using both modalities. Likewise, in an earlier, very careful study comparing radionuclide and ultrasound, McCarthy *et al.* (1970) have shown that whereas positive diagnosis of focal hepatic lesions is 95 % for radionuclide scanning and 90 % for ultrasound, it also approaches 100 % when both modalities are used.

There are many other such excellent studies in the literature, but the message remains the same and the experience in our hospital has certainly been comparable.





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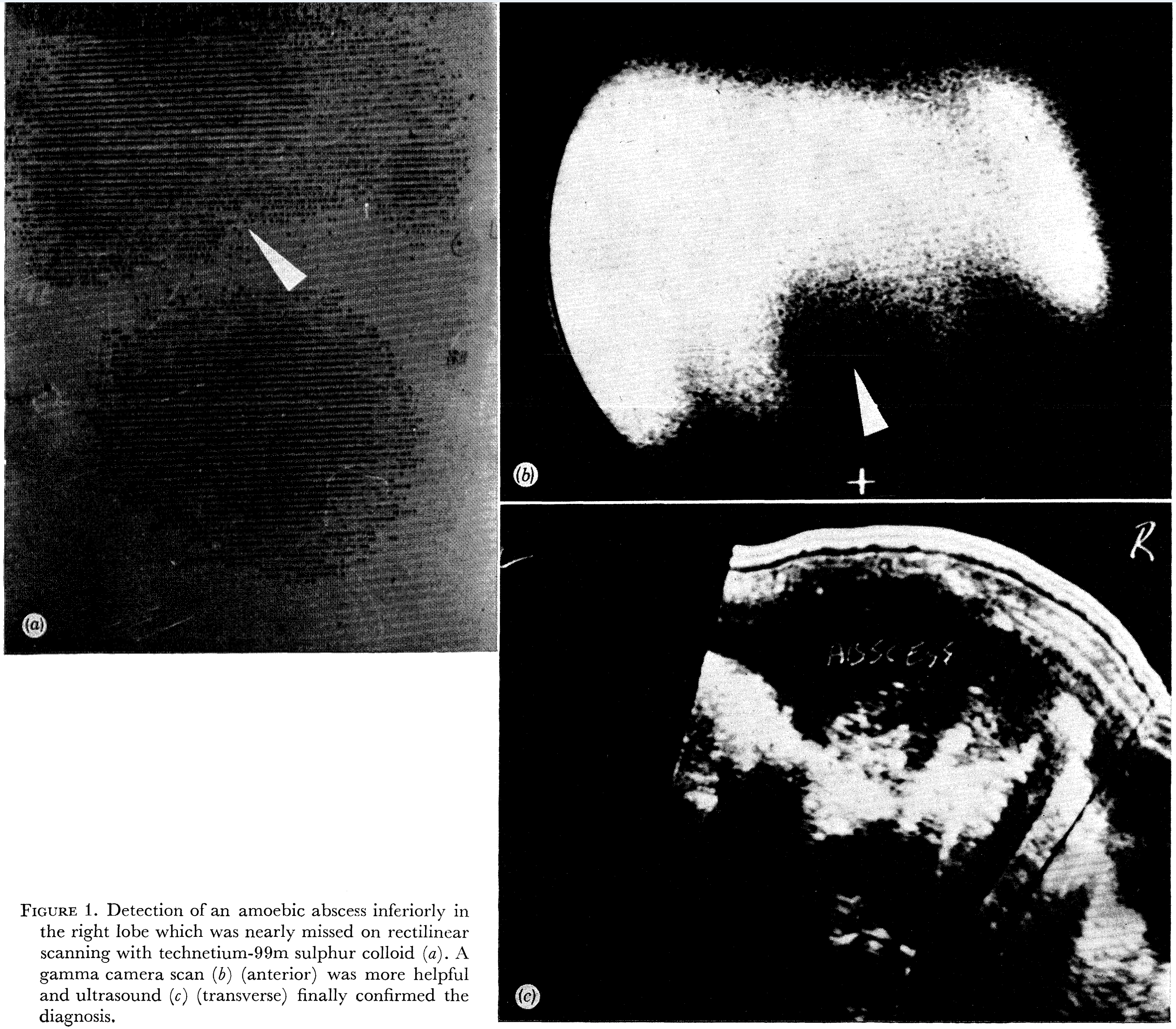
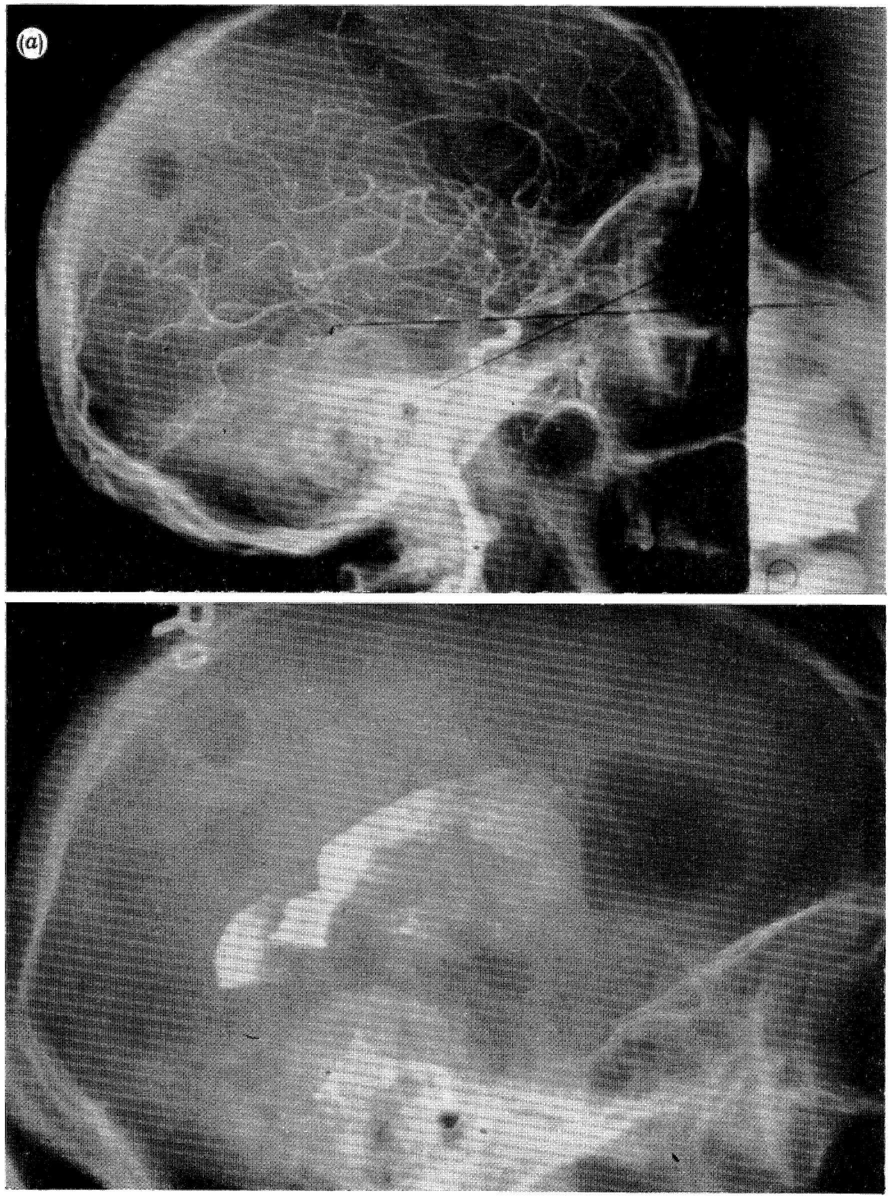



FIGURE 1. Detection of an amoebic abscess inferiorly in the right lobe which was nearly missed on rectilinear scanning with technetium-99m sulphur colloid (*a*). A gamma camera scan (*b*) (anterior) was more helpful and ultrasound (*c*) (transverse) finally confirmed the diagnosis.

right carotid angiogram

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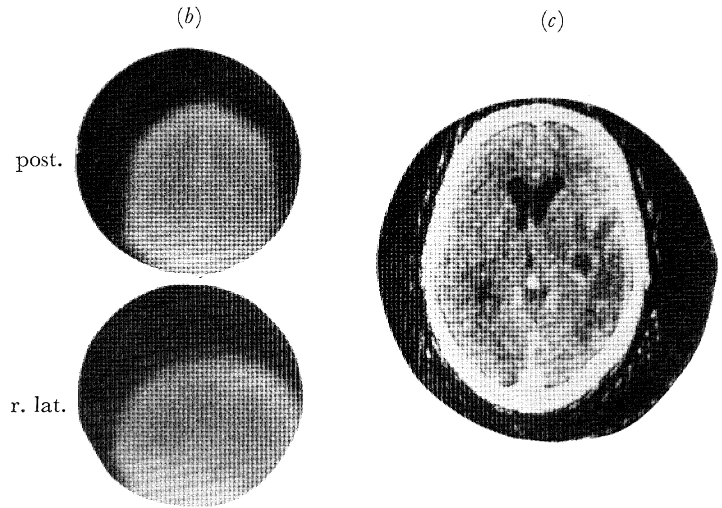
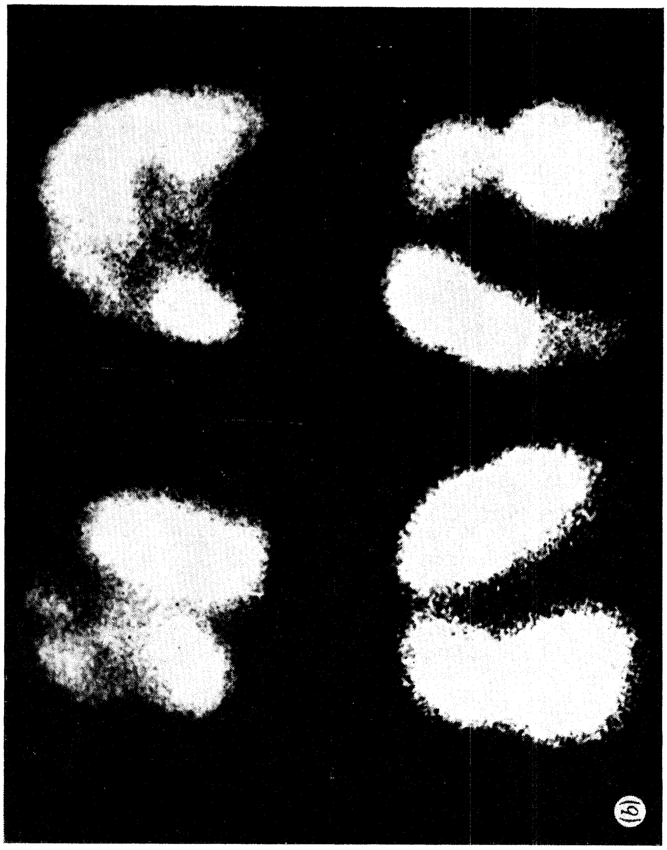
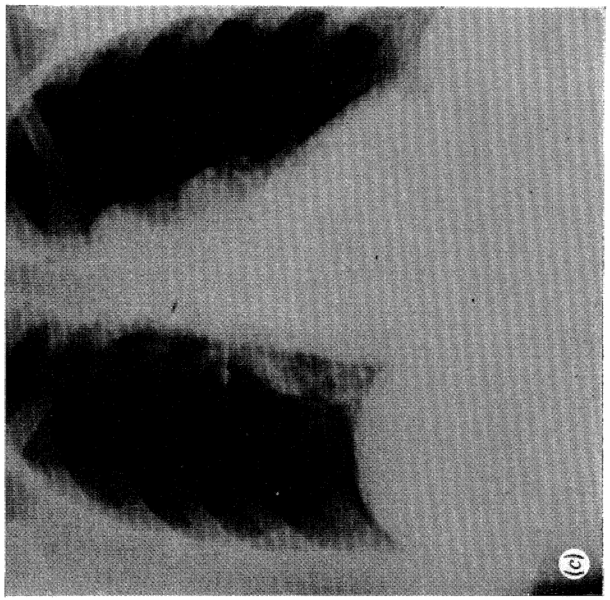



FIGURE 2. A patient with an abscess in the right posterior parietal area. The right carotid angiogram (*a*) and a radionuclide scan with the use of technetium-99m pertechnetate (*b*) were both relatively unhelpful, but the computed tomography study (*c*) was clearly positive.



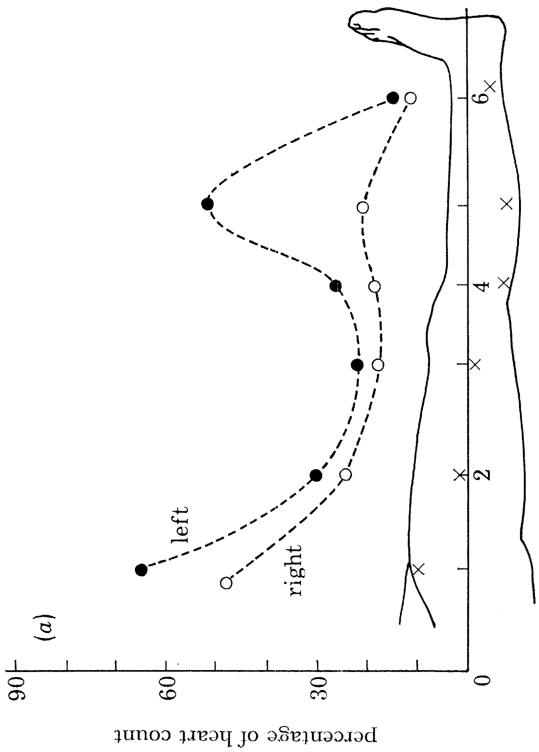




FIGURE 3. The classic situation seen in a patient with deep-vein thrombosis and pulmonary embolism: a positive uptake of iodine-125 fibrinogen in the left calf (*a*), wedge defects on the technetium-99m macroaggregated albumin perfusion scan (*b*) and a clear chest X-ray (*c*). Xenon-133 ventilation series was also normal.

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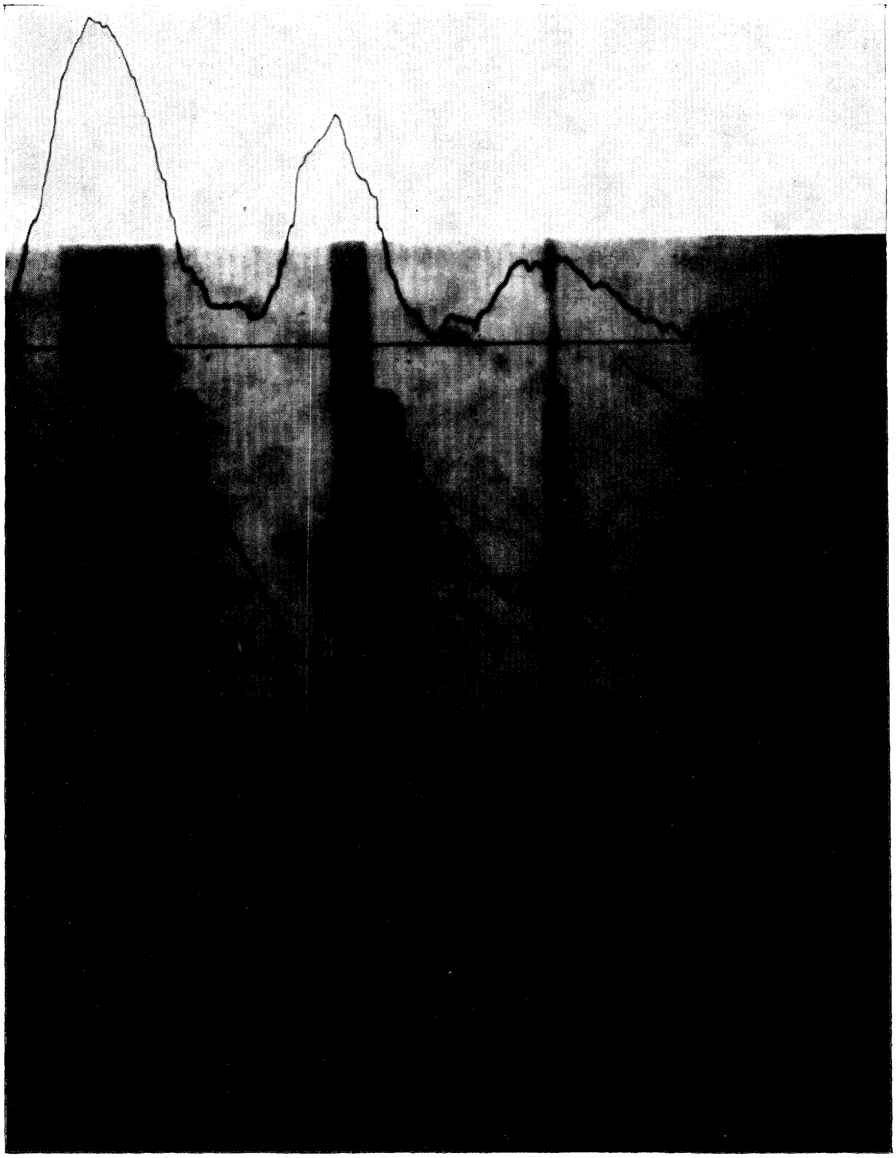

FIGURE 5. Typical transmission profile obtained during a traverse of a void-containing concrete block, superimposed on the appropriate X-ray photograph.



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Nowadays, of course, we also have whole-body computed tomography at our disposal. We have not been privileged to evaluate this modality ourselves, but once again statements similar to those quoted above for radionuclide and ultrasound are appearing in comparative series involving computed tomography. For example, MacCarty *et al.* (1977) have stated that the information obtained from simultaneous interpretation of computed tomography and technetium-99m sulphur colloid scans 'was often more valuable than the information obtained from either one alone, and in this sense the two techniques are complementary'. In their study comparing radionuclide scanning and computed tomography in 13 liver masses, 85 % were positive with either modality used separately. However, by employing both in combination, the detection rate rose to 92 %.

One of the most revealing studies of the liver with the use of radionuclide scanning, ultrasonography and computed tomography has been made by Grossman *et al.* (1977), who studied 50 patients with suspected liver disease, 35 of whom had confirmed intra-hepatic space-occupying lesions. The diagnostic efficacy of the different modalities were scored on a 0–5 scale in terms of detection value with the following results: ultrasound, 3.61; radionuclide, 3.11; computed tomography, 2.77.

It would therefore appear that in the case of the liver we have, in terms of St Paul, to hold fast to ultrasound, and in fact a combination of ultrasound and radionuclide scanning again identified all lesions.

## Cerebral lesions, especially inflammatory

While ultrasound dominates the hepatic scene, this is certainly not the case with cerebral lesions. A-mode echography is, of course, of considerable use in detecting midline shifts associated with head trauma, the detection of space-occupying lesions, the follow-up of known lesions and the evaluation of ventricular enlargements, but it does not compete in any real way with computed tomography or radionuclide brain scanning.

Compared to computed tomography, radionuclide scanning is cheaper, the equipment is more versatile and readily available, no contrast is required and no morbidity is associated with the technique. In the case of cerebro-vascular disease, Krishnamurthy *et al.* (1977), in a very provocative study, have compared radionuclide scintigraphy (including qualitative, quantitative, static and dynamic studies), angiography and computed tomography and have emerged with the respective accuracy figures of 72, 69 and 50 %.

Nevertheless, there is no doubt that computed tomography is a much more useful technique which is capable of producing high-resolution images over a wide range of disease states. There is good anatomical delineation and discrete placement of lesions, with the additional advantage of density quantitation as an aid to diagnosis. Secondary evidence of disease is often also apparent. For instance, with a cerebral abscess it is often possible not only to obtain intense enhancement of the abscess capsule, but also, if this were not the case, much could be deduced from mass displacement of structures and the associated cerebral oedema – the so-called intracranial suppuration triad (Joubert & Stephanov 1978).

Compared specifically with radionuclide scanning, computed tomography is slightly more sensitive, as specific and considerably more accurate. However, here again, a combined study is often more valuable than either alone. Jefferson & Keogh (1977) have stated that the overall mortality (for cerebral abscess) was 28 % in their series, that they regarded this figure as quite unacceptable and stressed that 'the combination of isotope scans and computerized axial tomography should allow an immediate reduction in mortality to around 10 %. The results of Christie *et al.* (1976), reproduced in table 1, show that in the detection of neoplasia, vascular-occlusive disease, cerebral haemorrhage, vascular anomalies, infection and trauma, the combined study always gives a higher yield than either alone. In another study of 25 posterior fossa tumours studied by Mikhael & Mattar (1977) 92 % were detected by radionuclide techniques and 88 % by computed tomography. Again, 100 % detection was achieved when both techniques were combined.

TABLE 1. COMPARATIVE ACCURACY OF RADIONUCLIDE SCANNING (r.n.) AND COMPUTED TOMOGRAPHY (c.t.) IN THE DIAGNOSIS OF INTRACRANIAL DISEASE

(From Christie *et al.* 1976)

| type of lesion | number of cases | accuracy (%) | | |
|---|---|---|---|---|
| | | r.n. | c.t. | both |
| neoplasm | 114 | 83 | 85 | 89 |
| vascular occlusive disease | 52 | 62 | 52 | 71 |
| brain haemorrhage | 13 | 54 | 100 | 100 |
| vascular anomalies | 5 | 80 | 80 | 100 |
| infection | 5 | 100 | 100 | 100 |
| trauma | 11 | 82 | 82 | 100 |

In the specific case of abscesses, detection by both radionuclide scintigraphy and computed tomography appears to be about 100 % in most series. However, in our own studies we have had cases of herpetic, viral and bacterial meningitis and multifocal encephalitis which have been positive on radionuclide scan, but negative on computed tomography, even with contrast enhancement as advised by Zimmerman, Patel & Bilaniuk (1976) for the demonstration of cerebritis. In fact, we have found radionuclide scanning very useful at the cerebritic stage of the disease and in following the progress of the lesion. Serial studies are particularly useful in showing the sequence of cerebritis, the cystic appearance of the fullblown (and possibly optimally operable) lesion, shrinking and final resolution.

However, there seems to me no question that for the detection of cerebral lesions, even though cross-modality screening is again important, computed tomography reigns supreme. See, for example, figure 2, plate 2, where the carotid angiogram was largely unhelpful, the radionuclide scan only slightly less so, and computed tomography supplied the correct answer. Although the latter technique has the disadvantages of inflexible positioning, motion sensitivity and is subject to a wide range of artefacts, there is no doubt that this is where we hold fast in this case. Even its expense, the fact that it is not entirely free of risk via its necessity for contrast enhancement, that it may engender overconfidence and that it is (at present!) limited to the static mode will not influence my opinion too greatly.

I also feel, as do Weinstein, Alfidi & Duchesneau (1976) that when computed tomography is available, the relatively uninformative skull radiograph should be dispensed with entirely, except after the computed tomography examination to evaluate further areas adjacent to dense bone which may not be ideally visualized because of artefacts.

However, because of my basic affinity for nuclear medicine, I must just mention the radionuclide counterpart of transmission-computed tomography, namely emission-computed tomography, and its immense potential, in association with positron scintigraphy, in the evaluation





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of organ function with the use of the biologically important short-lived isotopes of carbon, nitrogen and oxygen. Dare I look forward to a day in the not-too-distant future when we shall be able to see a section of the head showing the functional distribution of a labelled metabolite superimposed on the exquisite anatomical resolution of a transmission computed section?

### Deep-vein thrombosis and pulmonary embolism

Many clinicians are not convinced about the efficacy of low-dose heparin in preventing post-operative thrombo-embolism. For the last two years the Thrombo-embolism Study Group at the Groote Schuur Hospital and the University of Cape Town Medical School has undertaken an ongoing prospective study of a homogeneous patient population at risk, namely patients over the age of 40 years undergoing major, elective, intra-abdominal surgery. After informed consent, 297 patients were randomized into a control group and two prophylactic groups: low-dose heparin (5000 units pre-operatively and 5000 units three times daily thereafter) and sodium pentosan polysulphate (Tavan SP-54 (Noristan Laboratories), 50 mg, 14 and 2 h pre-operatively and 50 mg twice daily intramuscularly thereafter).

Table 2. Examples of the scoring system

| test results | | score out of 6 |
|---|---|---|
| before and after operation: normal chest radiograph, normal scan, normal spirometry | | 0 |
| before operation: normal chest radiograph, normal scan, obstruction on spirometry | after operation: normal chest radiograph, poorly defined scan defects | 1–2 |
| before operation: normal chest radiograph, normal scan, obstruction on spirometry | after operation: normal chest radiograph, well defined scan defects | 4–5 |
| before operation: normal chest radiograph, normal scan, normal spirometry | after operation: normal chest radiograph, well defined scan defects | 6 |

Pre-operatively an electrocardiograph, chest radiograph, technetium-99m macroaggregated albumin perfusion lung scan and spirometry were obtained and the iodine-125 fibrinogen uptake in the legs measured. Post-operatively the legs were examined daily with iodine-125 fibrinogen uptake and Doppler ultrasound. On the sixth post-operative day bilateral ascending venography and a chest X-ray were obtained and on the seventh day a perfusion scan and electrocardiograph. Selected patients also had xenon-133 ventilation lung scans and sequential perfusion scans. These results were assessed blind and a numerical score on the scale 0–6 recorded for each patient, reflecting the likelihood of pulmonary embolism in the following way: 0, definitely no pulmonary embolism; 1–3, possible pulmonary embolism; 4–5, probable, but not absolutely definite pulmonary embolism; 6, undoubted pulmonary embolism.





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Examples of how the scoring system works is given in table 2, based on the well known rationale that to establish pulmonary embolism the diagnostic triad of a positive perfusion scan, plus a negative ventilation scan and clear chest radiograph in the region of any perfusion defect, must be approximated. In our study, because of the extent of the trial, spirometry was largely substituted for ventilation scans, the latter only being carried out in selected doubtful cases. However, it should be pointed out that our scoring system is deliberately loaded against pulmonary embolism in order to avoid overdiagnosing minor changes and the method, therefore, probably underestimates the frequency of small pulmonary emboli.

Examples of a positive iodine-125 fibrinogen uptake test and a positive technetium-99m macroaggregated albumin perfusion lung scan are depicted in figure 3, plate 3.

The results of the trial to date indicate that the incidence of pulmonary embolism in both control and treated groups (heparin and sodium pentosan polysulphate) is not statistically different on the basis of a maximal-yield $\chi^2$ test. The heparin and sodium pentosan polysulphate group incidences of deep-vein thromboses were significantly less than the control group ($P < 0.01$), but apparently there was little to choose between the two modes of therapy.

Looking at the diagnostic visualization methods for detection of deep-vein thromboses, venography was the only sure way of detecting thromboses. Doppler ultrasound had only a 9.8% positive correlation with venography, with an alarming 90.2% false negative rate. (We incidentally found thermography to yield results in this same range.) The iodine-125 fibrinogen uptake test was somewhat better with 87.8% positive correlation, 8.1% false positive rate (usually owing to superficial thromboses and clot in the calf-plus-popliteal region) and 4.1% false negative rate. Only 7.8% of the patients depicted clinical symptoms or signs, a fact which should interest the clinicians.

It would therefore seem that in this study we hold fast to conventional röntgenology and radionuclide scanning, the former dominating the detection of deep-vein thromboses and the latter for diagnosing pulmonary embolism. However, the latter will not suffice without its concomitant chest radiograph, while the iodine-125 fibrinogen uptake is still the best screening method for detecting deep-vein thromboses.

## Flaws in concrete

Here I am on somewhat shakier ground, but I have nevertheless been intrigued to discover that the same diagnostic visualization techniques that are familiar to us in medicine can also be applied to the civil engineering field. A final-year engineering student, B. Black, was faced with the on-site problem of helping to detect flaws in the concrete used for dam walls and came to us for advice on available instrumentation.

I will not say too much about the methods used in the non-destructive examination of concrete except that these include ultrasonic tests, acoustic emission tests, surface impact tests, electrical and magnetic methods and the use of the electromagnetic radiations. The latter bring us to more familiar ground, and after using thermography and ultrasound to little avail, it was finally discovered that a combination of gamma-ray transmission methods and industrial X-radiography provided the answer. Ultrasonic recordings provided a clear indication of the flaws, but the repeatability was not good owing to the sensitivity of the method to grit on the surface.

Black (1977) then continued to investigate the problem in the laboratory with a gamma-ray inspection test rig, whereby the source and scintillation detector could maintain a constant relative position as the beam traversed a concrete block. The concrete sample blocks were passed through the beam at a constant rate on a sample trolley regulated by a servocontrol mechanism.

The concrete sample blocks (figure 4) were cast containing polystyrene voids of different sizes, and the relative position and dimensions of these voids could be marked on the recording trace by using a replica of the void sheet fixed to the side of the trolley in a position that caused correspondence between the position of the gamma-ray beam and the sensor on the template.

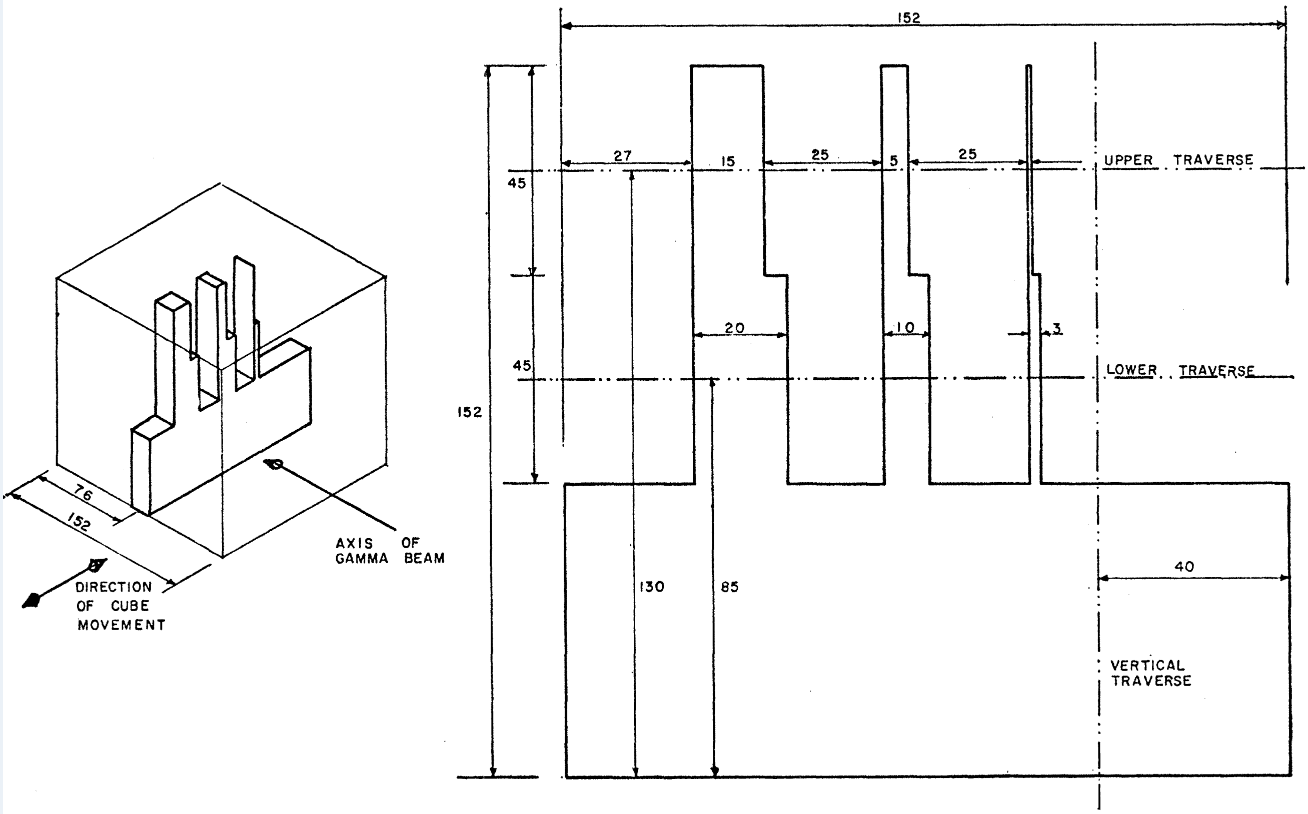


FIGURE 4. Drawing of an experimental concrete block (left: isometric view) showing position of polystyrene voids and levels of traverse. Measurements are in millimetres.

The interruption of a light beam caused the expected position of the void to be marked on the recorder.

Three traverses were made on each cube for void sheets of 20, 15, 10, 8, 5 and 2 mm thickness. The first line scan was designed to pass through the 15, 5 and 2 mm thick voids, while the second line scan was designed to inspect the 20, 10 and 8 mm voids. For the third line scan the concrete cube was turned on its side and the difference in penetration between the solid concrete and a sheet void was detected. Void-containing concrete blocks 150, 300 and 450 mm thick were each tested with three gamma-ray sources: 6 mCi cobalt-60, 30 mCi caesium-137 and 5 mCi iridium-192. An example of a typical transmission profile, superimposed on the appropriate X-ray, is depicted in figure 5, plate 4.

As a result of his observations, Black (1977) came to the conclusion that for inspection of walls up to and including 200 mm thick, 5 mCi cobalt-60, caesium-137 or iridium-192 could be used. For inspecting concrete between 200 and 450 mm, a much larger source (e.g. 30 mCi caesium-137) is necessary to yield acceptable results. However, it was still possible to detect a 15 mm void in 450 mm concrete with a 6 mCi cobalt-60 source. With a 30 mCi caesium-137 source an 8 mm void is clearly visible.

In any event, in this situation, gamma-ray transmission methods appear to be the most sensitive.

## Conclusions

It can clearly be seen that while one diagnostic modality can be more efficient than another in a certain situation (e.g. ultrasound for hepatic lesions, computed tomography for cerebral lesions, constrast röntgenology for deep-vein thromboses, radionuclide scanning for pulmonary embolism, gamma-ray transmission for flaws in concrete), considerably improved diagnostic rates are possible if all of the available diagnostic modalities are used in an ordered and logical way.

Many of the successes of the past in both radiodiagnosis and radiotherapy have stemmed from cooperation between individuals at the level of the clinical problem. Now, more than ever, there must be total cooperation at the highest academic level between visualizing departments in the development of multi-modality approaches to diagnosis. This interaction must be taken to the point where inter-departmental diagnostic protocols are set up, with all that this implies for the future planning of hospitals.

I am indebted to Mr Bruce Black for permission to quote results from his thesis and to Professor E. Immelman, Dr S. Benatar, Dr D. P. Jeffrey and the other members of the Groote Schuur Hospital Thrombo-embolism Study Group for allowing me access to their latest results. This Group, of which I am also a participating member, has received financial assistance from the South African Medical Research Council, the University of Cape Town Staff Research Fund and Noristan Laboratories (Pty) Ltd, Pretoria, to all of whom I am deeply grateful.

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*Discussion*

A. Nemet (22 *Denbigh Gardens*, *Richmond*, *Surrey*, *U.K.*). Dr Shepstone has stressed the importance of multiple technique diagnosis because these techniques are complementary rather than self-contained; he has illustrated this with some case histories. Does this mean that all or most of his patients who require this diagnosis benefit from it, or are the examples given merely research cases? If the latter, does his statement not describe an ideal situation, impossible to achieve in practice?

B. J. Shepstone. As far as possible all of our patients reap the benefit of cross-visualization methods, and in fact it would be unethical to exclude anyone from this privilege. However, I have taken pains to point out that, depending on the working clinical diagnosis, there has emerged an established order or priority in which each modality is to be used. As soon as a satisfactory answer is found the investigations cease. The studies are never done simply to produce a series of interesting pictures, and in fact our basic premise is that anything which does not change the *a priori* diagnosis is not of very much help. However, it occasionally happens that clinicians need more security or else require better delineation of a lesion for surgical purposes, and only in this case would we take another look at something about which we are already fairly certain.

P. N. T. Wells (*Department of Medical Physics*, *Bristol General Hospital*, *Guinea Street*, *Bristol BS*1 6*SY*, *U.K.*). The question of the complementary nature of different diagnostic methods is an important one. It has to be remembered that in the 'blind' analysis of data obtained by different methods, the doctor's clinical impressions of the patients are deliberately excluded. When combined with clinical judgement, the accuracy obtained with a single physical method may become extremely high. Each of the different techniques has an optimum place in the diagnostic algorithm which should be chosen individually for each patient according to his symptoms. Moreover, in some clinical situations a particular technique dominates to the exclusion of others, as does ultrasonics in obstetrics. Nothing else is acceptable in a cost-limited health service.







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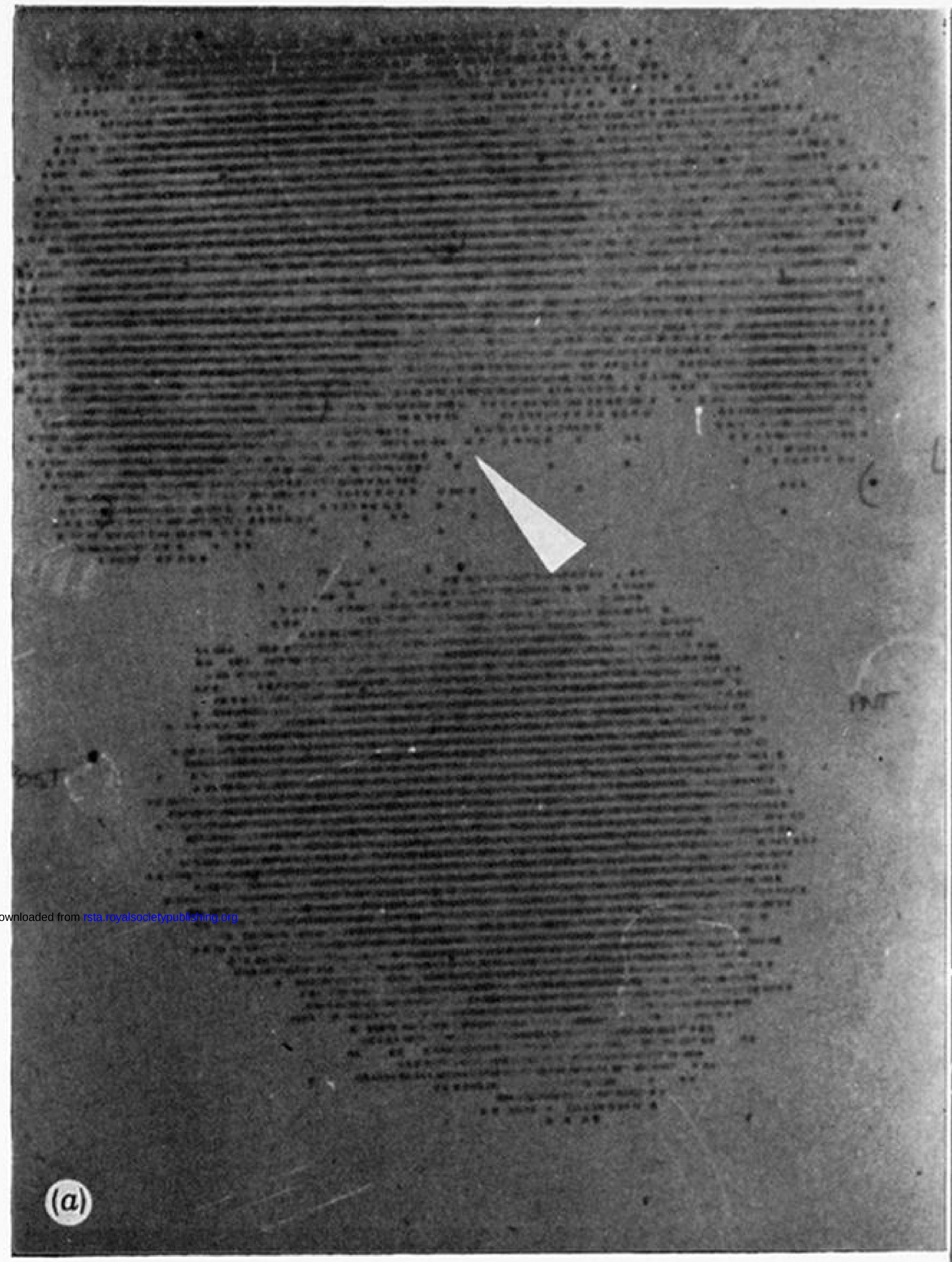


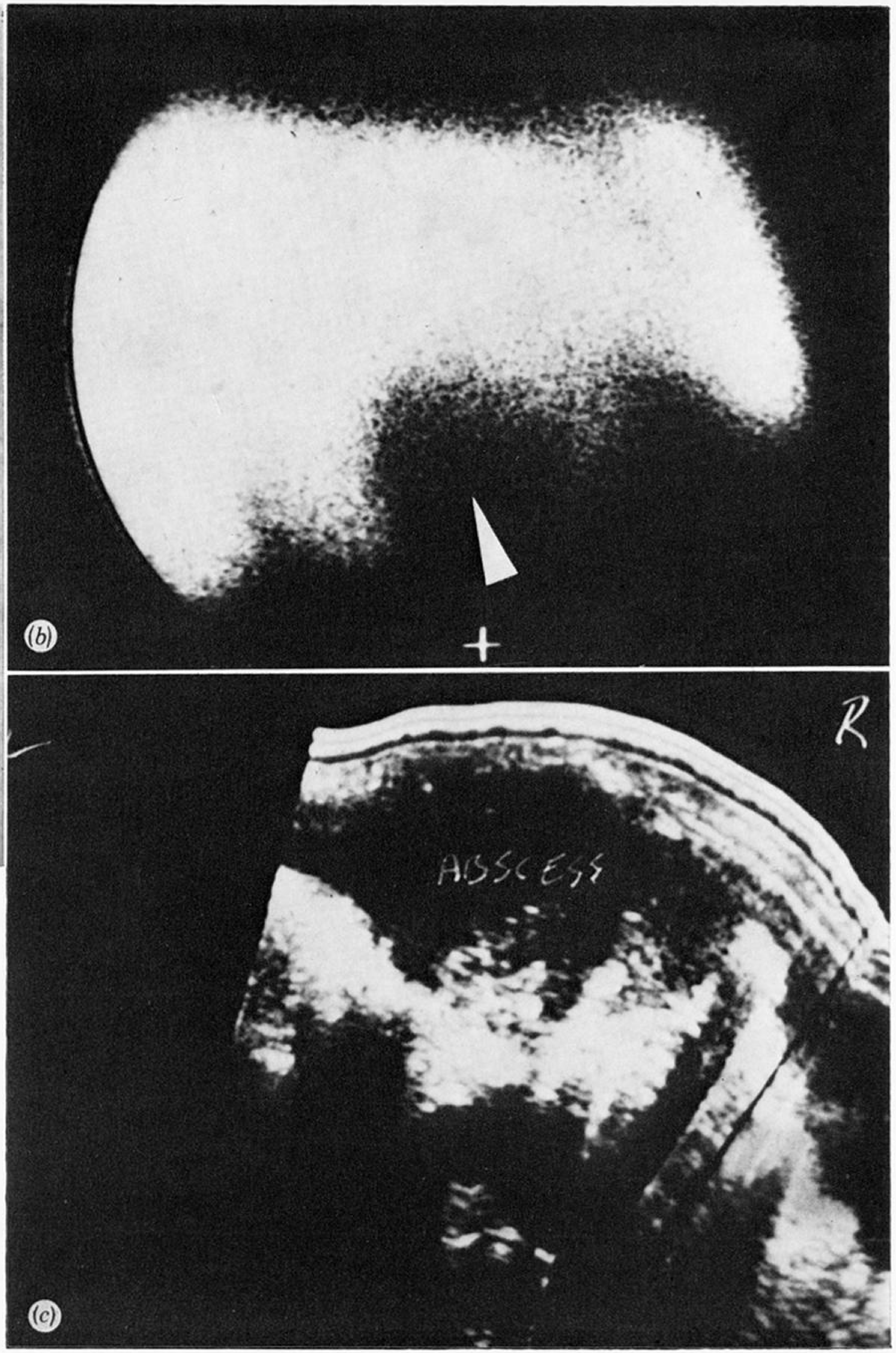


FIGURE 1. Detection of an amoebic abscess inferiorly in the right lobe which was nearly missed on rectilinear scanning with technetium-99m sulphur colloid (*a*). A gamma camera scan (*b*) (anterior) was more helpful and ultrasound (*c*) (transverse) finally confirmed the diagnosis.





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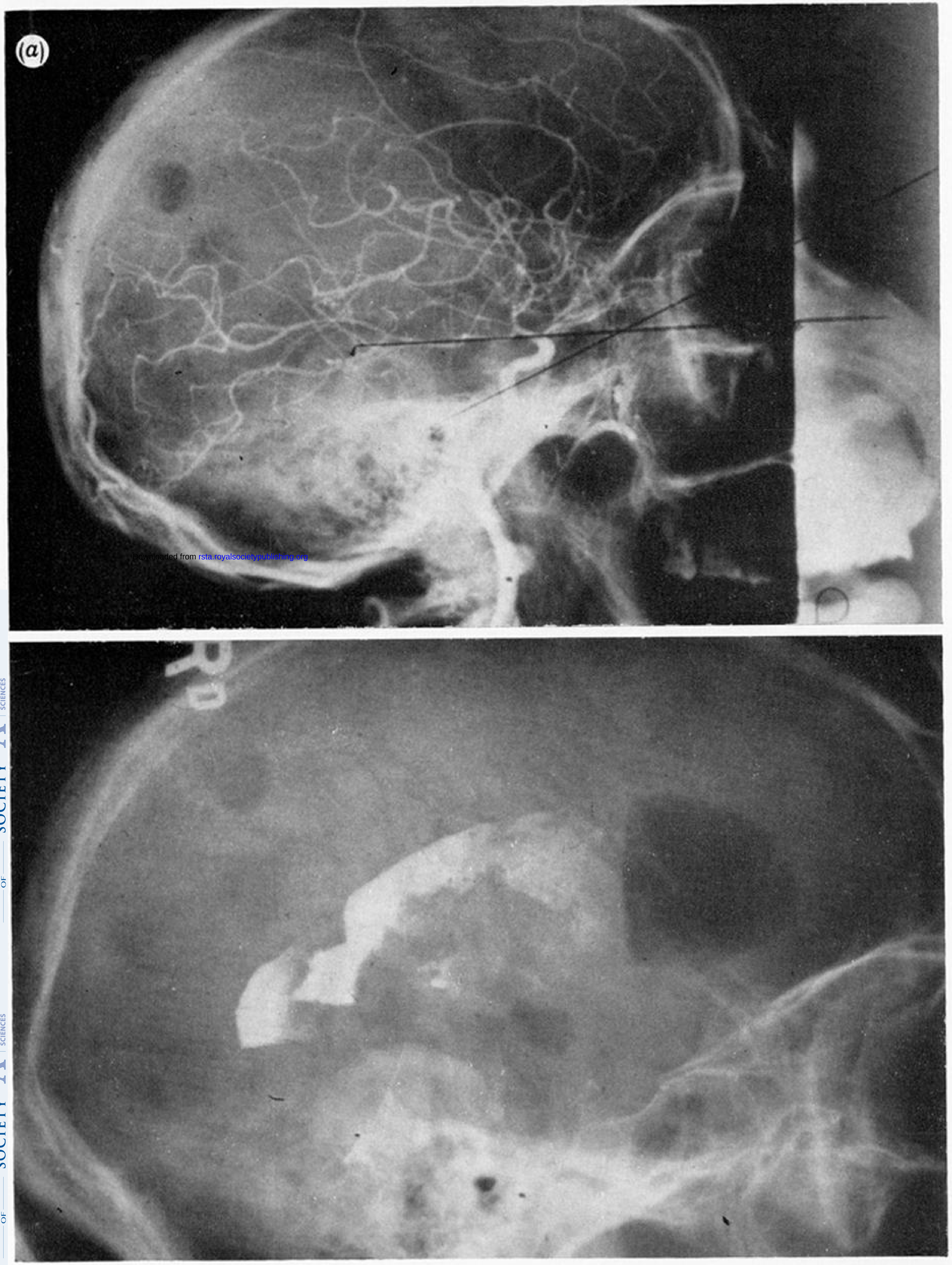
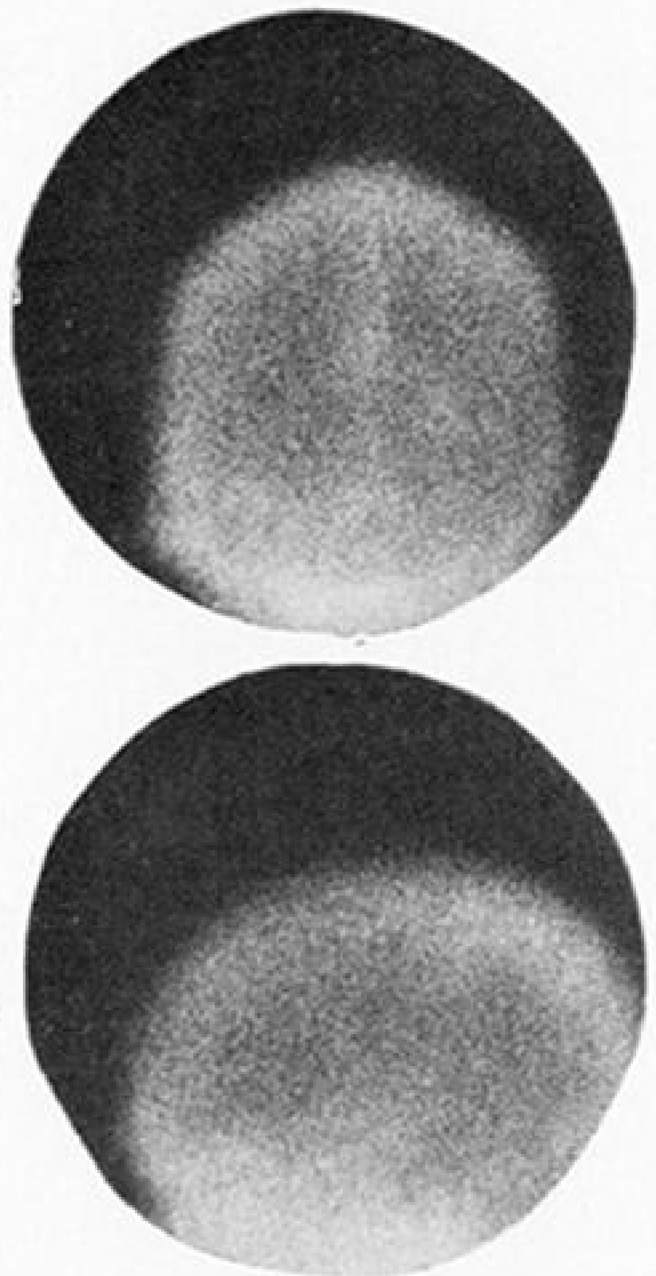
right carotid angiogram




pyogram

(b)




(c)

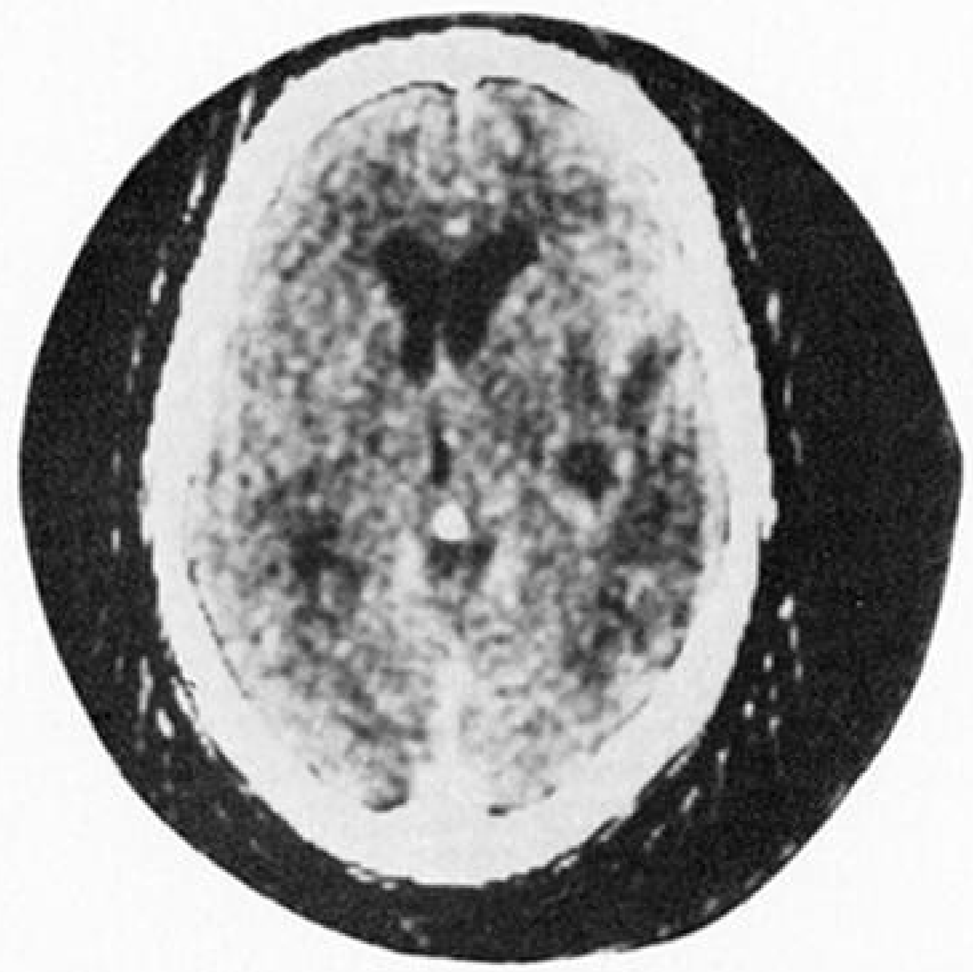
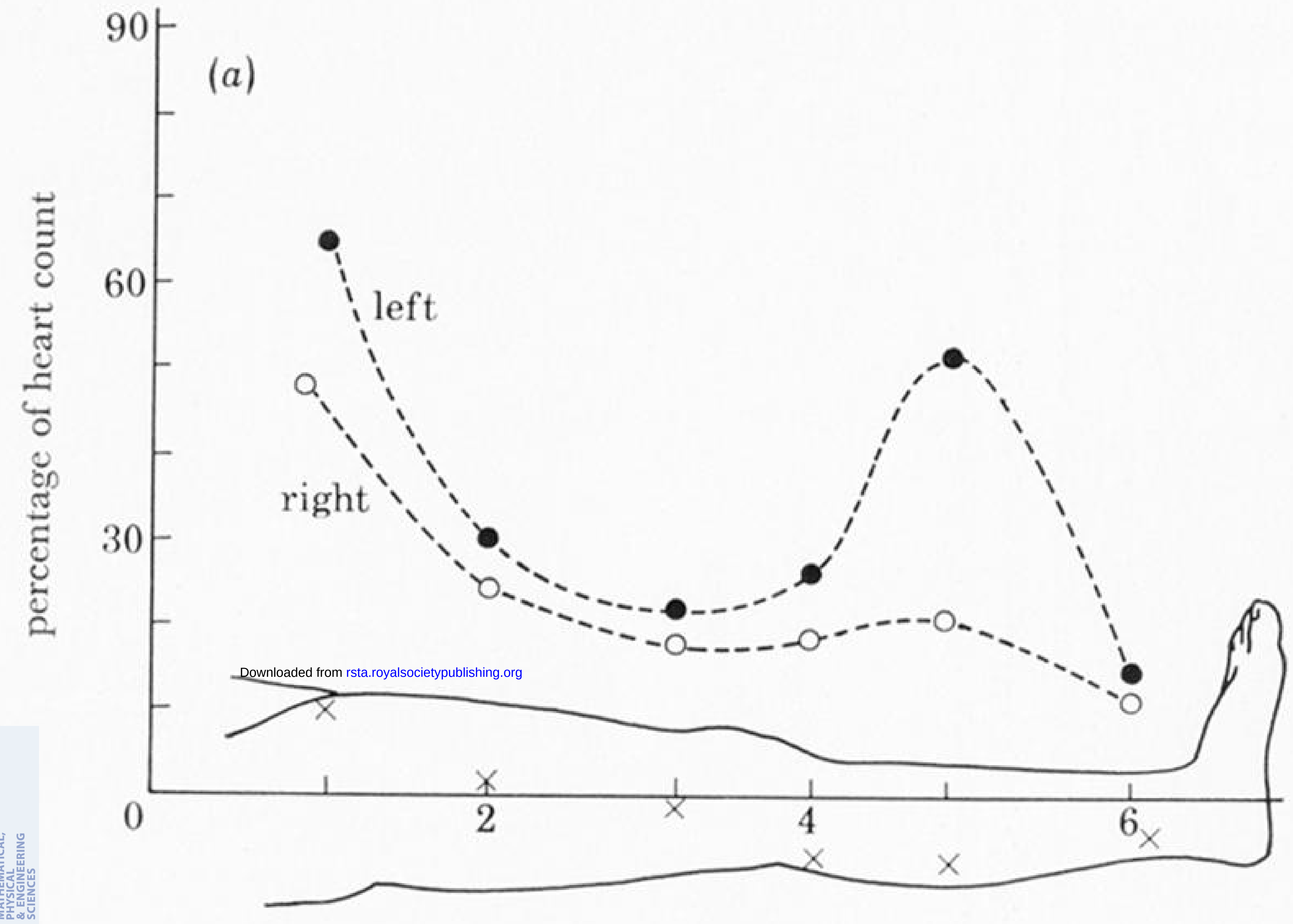


FIGURE 2. A patient with an abscess in the right posterior parietal area. The right carotid angiogram (*a*) and a radionuclide scan with the use of technetium-99m pertechnetate (*b*) were both relatively unhelpful, but the computed tomography study (*c*) was clearly positive.





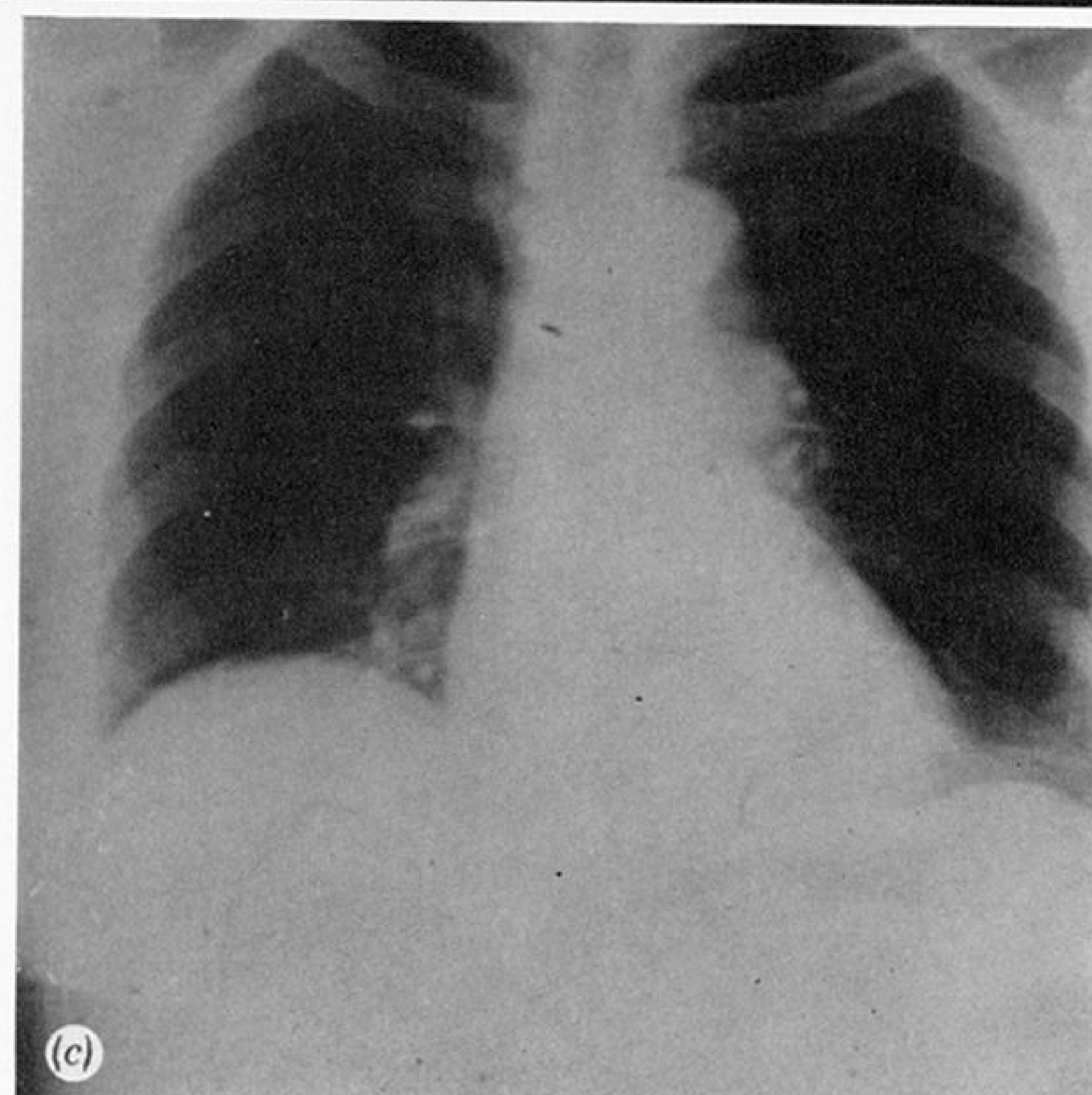



FIGURE 3. The classic situation seen in a patient with deep-vein thrombosis and pulmonary embolism: a positive uptake of iodine-125 fibrinogen in the left calf (*a*), wedge defects on the technetium-99m macroaggregated albumin perfusion scan (*b*) and a clear chest X-ray (*c*). Xenon-133 ventilation series was also normal.

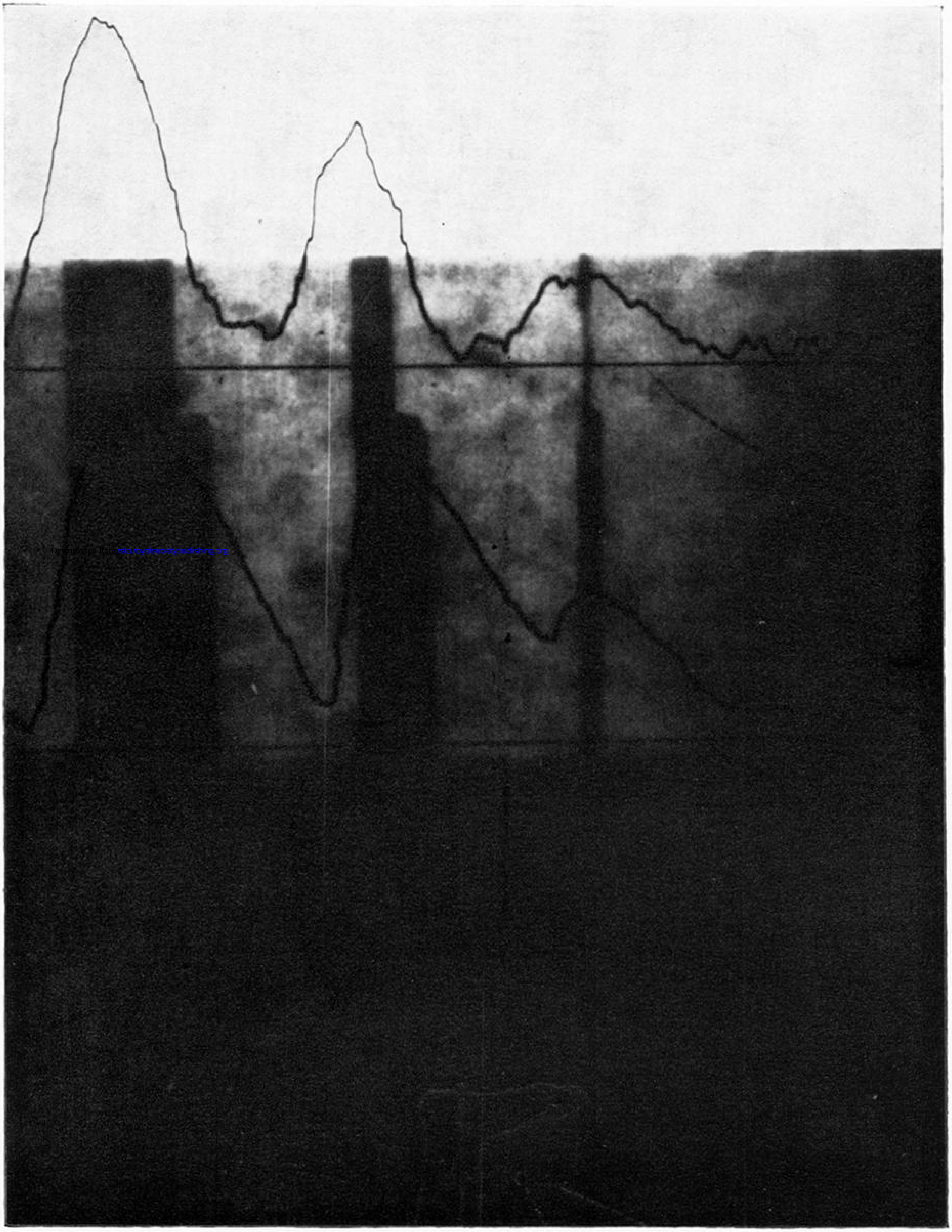


FIGURE 5. Typical transmission profile obtained during a traverse of a void-containing concrete block, superimposed on the appropriate X-ray photograph.