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DIAPHANOGRAPHY

Mechanism responsible for the images

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CUTLER (1929) was the first to show how transillumination of the female breast could be of value in defining the position of a lesion, particularly in cases of the bleeding nipple. He did point out the limitations of the technique notably the inability of the method at that stage to distinguish benign from malignant disease. The subsequent development of mammary radiography and its ability to localise microcalcification appears to have inhibited any further developments of diaphanography until a commercial company (Sinus Medical Equipment AB., Stockholm, Sweden) introduced an equipment some 3 years ago. The limitations of mammary radiography in the case of the young dense breast and increasing concern over the smallest radiation dose (MOLE 1978) has led to a reawakening of interest in diaphanography as a diagnostic supplement and in its own right in relation to the screening of 'well' women (STRAX 1980) by virtue of the fact that it utilises non-ionising radiation in the visible and near-infrared region of the spectrum. The method has two aspects. First is a visual inspection in a darkened room of the superior aspect of the breast with a light torch applied to the skin of the inferior surface. The objective is to locate any areas where there is a circumscribed shadow (neoplasm) or area of increased brightness (cyst). The second part of the examination is to make a colour infrared photographic record (Kodak Echtochrome infrared E4 process) using a 35 mm camera synchronsised to a xenon flash tube in the torch. OHLSSON et coll. (1980) point out that not only neoplasms and cystic lesions may be recognised by this technique but also areas of fibroadenosis by their characteristic intense cherryred colour.

Recently, ISARD (1980), OHLSSON et coll. and HUSSEY et coll. (1981) have encouraged the view that diaphanography has a valuable role as a supplement to mammary radiography. The colour images cover the range, yellow, orange, brown and black but hitherto there has been no adequate explanation of the mechanism(s) giving rise to the colour variations or of the association of a particular colour with each pathologic condition.

The present investigation set out to measure the transmission coefficient of slabs of material removed from the female breast at operation with the expectation that different lesions would transmit light to an extent dependent on the type of disease process. Large variations from sample to sample taken from the same lesion and the fact that there was no clear distinction between transmission characteristics of neoplastic and benign lesions showed that it was not the properties of the tissues and lesions themselves which were being imaged. The spectro-photometric traces in every case demonstrated the absorption bands of oxyhaemoglobin, a fact which led to a consideration whether in fact the number of red cells (erythrocytes) per unit volume was the factor leading to the characteristic colour-

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tion upon transillumination and also to colour changes due to pathologic change. The knowledge, WELLS et coll. (1977), that ultrasound Doppler signals arise from neovascularisation around malignant breast tumours reinforced the plausibility of this view. An investigation by spectrophotometry and infrared colour photography of human blood over a range of dilutions with normal saline is now described and implications for the use of diaphanography as a diagnostic tool are drawn.

Experimental

Samples 2 mm thick were cut from specimens removed at operation and placed in cuvettes (plastic 1 cm^2. Each sample was coded but the pathologist's report was unknown initially. The cuvettes were placed in a Cambridge Unicam SP800 UV-visible spectrophotometer. The transmission as a function of wavelength over the range 900 to 400 nm was plotted using a pen recorder for 9 samples, 7 being of thickness 2 mm. The other 2 were of 5 mm and 10 mm thickness. The per cent transmission was measured separately by placing in the cuvettes 3 mm thick samples of opal perspex (I.C.I. Welwyn Garden City, Hertfordshire England) of known transmission coefficient (T; COLINS & HARPER 1955). Fig. 1 shows the traces of different samples of tissue between 700 and 400 nm, indicating no obvious differenes in the values of T between neoplastic and benign disease. It is notable that curve (b) which related to a 2 mm sample had a higher value of T than (a) taken on a 5 mm sample from the same lesion. The curves d, f, h, i, j for benign disease had values of T in the same range as those from the samples taken from a carcinoma, a, b and c. At wavelengths of 576, 542 and 412 nm the absorption bands of oxyhaemoglobin can be clearly discerned in Fig. 1. The same bands are also seen in pork fat (e; CARTWRIGHT 1930). He found T=20 per cent at 1000 nm for a 5 mm sample. The same absorption characteristics are clearly visible in normal tissue (Fig. 1, curve g). Similar features in relation to the appearance of skin in reflected light have also been observed by EDWARDS & DUNTLEY (1930).

These findings indicated that nothing as simple as a variation in T was responsible for the features observed in images obtained by diaphanography but also suggested the need for a closer investigation of the transmission properties of blood over a range of concentrations. The rationale for this can be conceived by considering that in regions served by capillaries there are fewer red cells per unit volume than in those perfused by a multiplicity of veins and arteries.

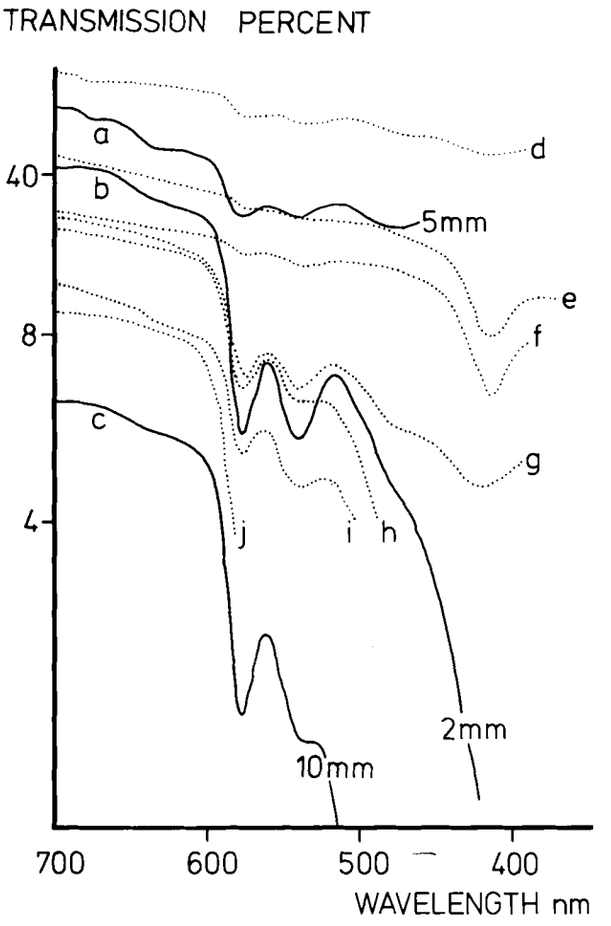

Fig. 1. Transmission measurements of different tissues, all specimens except (e) being removed at operation. a, b, c = carcinoma. g=normal breast. e=pork fat. All others from breasts with fibroadenosis. a=5 mm, b=2 mm, c=10 mm. All others = 2 mm.

Whole blood treated with citrate phosphate dextrose for anticoagulation was placed in spectrophotometer-type square section cuvettes (1 cm^2) at dilutions ranging from 1:2000 to whole blood. The cuvettes were placed between optically diffusing opal perspex sheets, each of transmission coefficient T=8 per cent (grade 069, 3 mm thick) and illuminated with a diaphanography torch. The sheets were aimed at simulating the diffusive nature of the skin. A flash synchronised 35 mm camera was focussed on the opal perspex in the same way as for a breast examination. The xenon flash tube was activated and the infrared colour film exposed in

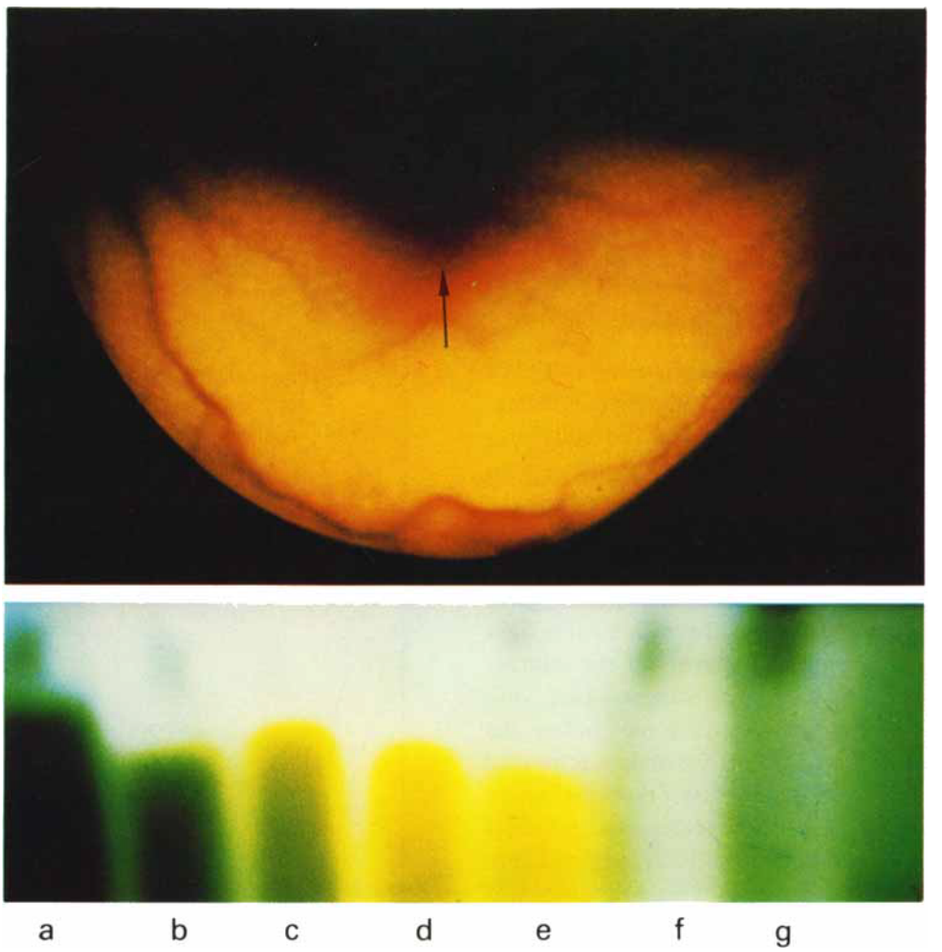

Fig. 2. The upper image is a typical representation of a breast with a carcinoma (→). The lower image is formed by transilluminating specimens of whole and diluted blood. The good colour match between these images strongly supports the view that the blood cells influence the appearance of the image. The infrared film transposes the image into pseudo-colour.

synchrony. After development of the film a range of colours (Fig. 2) similar to those observed in breast examinations was found indicating that the diagnostic procedure does in fact monitor the number density of red cells. Whole blood was strongly absorbing showing up black. With increasing dilution colours of brown, yellow and straw-colour were observed. The fact that upon transillumination of breast, straw-colour is never observed probably arises from the richness of capillary loops in the dermal papillae, which gives a lower limit to the density of red cells in the optical path of the torch (BERRES 1837). The investigation, thus far, suggests that the spatial average density of red cells is intimately connected with the colour observed when tissues are illuminated with white light.

An obvious extension of the experiments was a spectrophotometric analysis of samples of diluted blood. The samples, imaged in Fig. 2, were inserted one at a time in the Cambridge Unicam SP8-100 Spectrophotometer. Samples with dilutions 1 : 2 000 (g), 1 : 1 000 (f), 1 : 100 (e), 1 : 10 (d), 1 : 5 (c), 1 : 2 (b) and whole blood (a) were analysed as a function of wavelength. Samples (a) to (e) were scanned on the same settings but (f) and (g) were examined separately on different settings because of the limitations of the instrument. For samples (a) to (d) the cut-off was in the red and orange band of the visible spectrum (Fig. 3). The cut-off for sample (e) was in the blue end of the violet. Samples (f) and (g) had no cut-off. These experiments provide excellent confirmation of how red cell densities in effect provide a range of colour filters and suggest that generally speaking the red cell density has an average value

not exceeding a figure of around 1 : 10 in the breast. Clearly pathologic conditions with a proliferation of vessels increase the red cell density thereby intensifying the red colouration or (in the case of neoplasm) cutting of the light altogether giving black (colouration) in the images. Superficial veins also show up black.

Discussion and Conclusions

The present experiments have provided evidence of why colour infrared film is advantageous in imaging lesions by diaphanography. The red cells provide in effect a colour filter with a cut-off between the yellow and red part of the spectrum. Variations in optical density in the red part of the spectrum is best recorded on film extending into the near infrared region (~900 nm). Additionally the colour of images formed by diaphanography with a white light source has been explained in terms of the number density of red cells. This finding suggests that cooling of the skin and subcutaneous tissues before the examination and consequent vasoconstriction of vessels may assist the examination in cases where the breast is dense at optical wavelengths by reducing the number density of red cells. It is intended to look at this possibility in a future investigation. It is to be expected that in cases of neoplasm the advancing front of the lesion will be outlined. In cases where biopsies have been carried out before diaphanography intense black colouration (total absorption) is observed due to bleeding. Clearly such examinations by diaphanography are preferable before biopsy. The appearance of cysts (bright yellow against a darker background) can be explained by the fact that the lesions expand pushing aside tissues containing light absorbing blood vessels. Further examinations of normal and pathologic samples of breast tissues are called for and the possibility of carrying out some form of in vivo spectrophotometry must be borne in mind. These experiments were restricted to a particular wavelength range of the electromagnetic spectrum. Further basic investigations of the near infrared region could be rewarding.

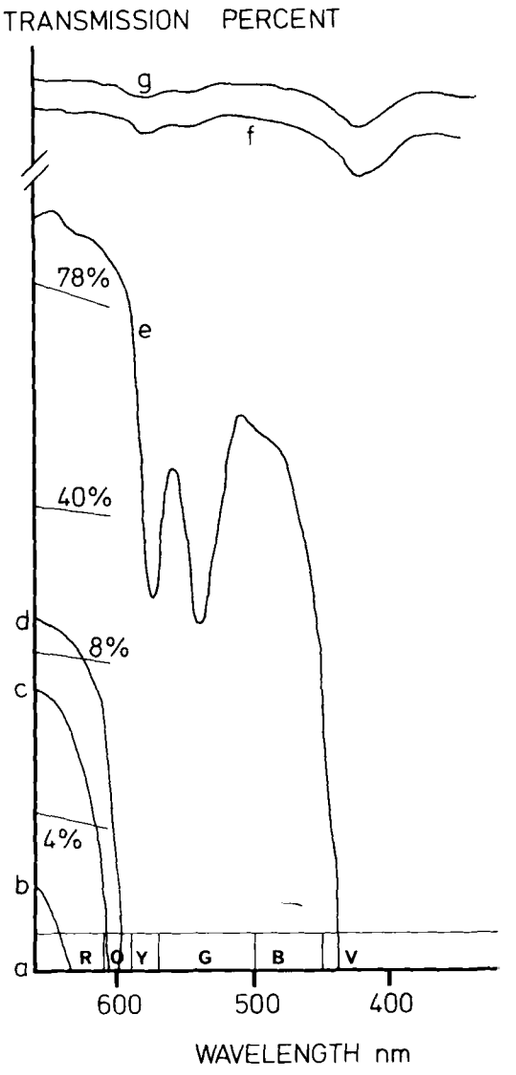

Fig. 3. Spectrophotometric traces obtained with blood at a range of dilutions indicating optical cut-offs whose wavelength depends on the dilution factor. R=red. O=orange. Y=yellow. G=green. B=blue. V=violet. g=1 : 2000. f=1 : 1000. e=1 : 100. d=1 : 10. c=1 : 5. b=1 : 2. a=1 : 0.

SUMMARY

Preliminary measurements showed that spectrophotometry of samples of tissue taken at operation from the female breast demonstrated no obvious correlation between transmission coefficient and pathology, except that thicker samples tended to transmit less light than thinner samples. However all the samples had absorption minima corresponding to the bands of oxyhaemoglobin. This simple fact led to the speculation that the density of blood in the tissues, (number of red cells per unit volume) was the factor giving rise to different colours of breast tissues and of breast pathology observed upon transillumination with white light in vivo. Examination by infrared colour photography and by spectrophotometry of transilluminated samples of blood diluted with normal saline confirms that the observed colour is dependent on red cell concentration.

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REFERENCES

BERRES: Anatomica microscopia corporis humani. Vienna 1837.

CARTWRIGHT C. H.: Infra-red transmission of the flesh. J. Opt. Soc. Amer. 20 (1930), 81.

COLINS P. H. and HARPER W. E.: Transmission measurements on opal materials. Trans. Illum. Eng. Soc. 20 (1955), 109.

CUTLER M.: Transillumination as an aid to diagnosis of breast lesions. Surg. Gynec. Obstet. 48 (1929), 721.

EDWARDS E. A. and DUNTLEY S. Q.: The pigments and colour of living human skin. Amer. J. Anat. 65 (1930), 1.

HUSSEY G., MACDONALD A. F., NICHOLS D. and WATMOUGH D. J.: Diaphanography. A comparison with mammography and thermography. Brit. J. Radiol. 54 (1981), 163.

ISARD H. J.: Diaphanography of the breast revisited. Proceedings of the meeting of the Society for Study of Breast Diseases. Philadelphia 1980.

MOLE R. H.: The sensitivity of the human breast to cancer induction by ionizing radiation. Brit. J. Radiol. 51 (1978), 401.

OHLSSON B., GUNDEISON J. and NILSSON D.: Diaphanography. A method of evaluation of the female breast. World J. Surg. 4 (1980), 701.

STRAX P.: Invited commentary. World J. Surg. 4 (1980), 701.

WELLS P. N. T., HALLWELL M., SKIDMORE R., WEBB A. J. and WOODCOCK J. P.: Tumour detection by ultrasonic Doppler blood flow signals. Ultrasonics 15 (1977), 231.