# ORIGINAL PAPERS

## Thermography as an aid to cryosurgery

by P. F. Bradley

*Department of Oral Surgery, University of Liverpool and Broadgreen Facio - Maxillary Unit, Liverpool (England)*

**SUMMARY. Thermography may be used as a method of monitoring therapeutic freezing procedures in the tissues. Three basic viewing positions are described; depth viewing, surface viewing and contralateral viewing. The following uses of thermography in connection with cryosurgery have been defined: 1) Comparison of cryosurgical methods; 2) Study of the effects of tissue temperature gradients; 3) Clinical monitoring; 4) Early prediction of the zone of necrosis.**

**Key words: thermography, cryosurgery, thermocouples, calibration curves.**

It is readily possible to destroy unwanted tissue by the application of sub zero temperatures with modern cryosurgical apparatus. Cryosurgery can thus be used for the treatment of a variety of hyperplastic and neoplastic lesions. One of the problems in this field is that of control and, predictability of effect and this is particularly important in the treatment of malignant disease [1]. Smith and Fraser [2] suggested that, within an ice-ball, only the tissue inside the minus 15° isotherm will eventually undergo necrosis. For effective treatment and for research purposes it would be of advantage to be able to plot this and related isotherms during freezing. Thermocouples are traditionally used for such monitoring, but they are not without some disadvantages — for example: (a) they only make sample recordings and one has to make some assumptions about the intervening areas; (b) they may be difficult to position in some tissues, particularly bone; (c) they can alter the physical characteristics of the tissue especially if multiple couples are used; (d) the passage of the needle thermocouple could cause neoplastic seeding.

To overcome some of these problems, work has been undertaken in the Department of Oral Surgery of Liverpool University to explore the use of thermography as a means of monitoring the progress and characteristics of the cryogenic process in tissue. Thermographic evaluation of methods of freezing bone has been described by our unit [3]. The object of

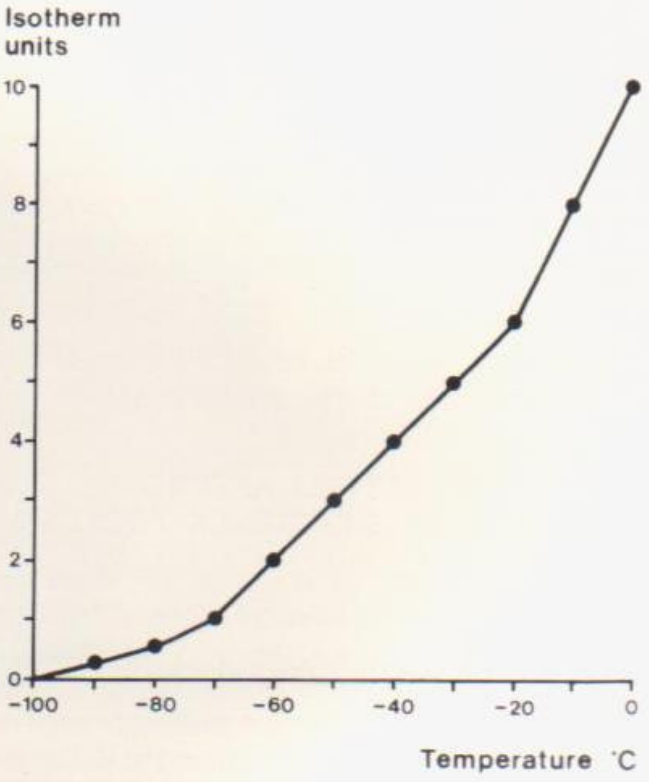


Fig. 1. Curve of isotherm units versus temperature for subzero temperatures (Aga 680, f 1.8).

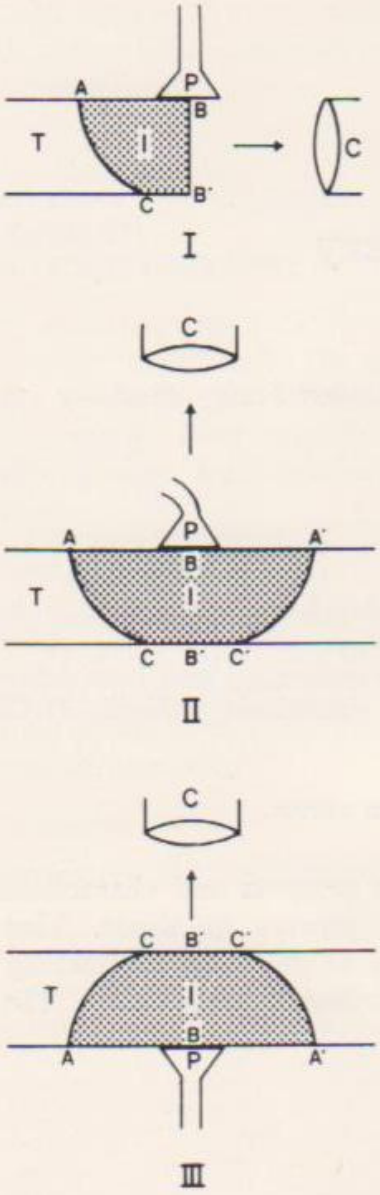


Fig. 2. Basic viewing positions (P: cryoprobe; T: tissue; I: iceball; C: thermographic camera). I) DEPTH VIEWING monitors dimension BB'. II) SURFACE VIEWING monitors dimension AA'. III) CONTROLATERAL VIEWING monitors dimension CC'.

this article is to outline initial findings over a wider range of cryosurgical applications.

## TISSUE EMISSIVITIES AND LOW TEMPERATURE REFERENCE POINT

Our experiments show that at subzero temperatures the emissivities of such tissues as skin, mucosa and muscle are very comparable. The emissivity of bone is marginally lower than that of the soft tissues although once a layer of frost forms on the tissues, the difference is minimal.

One needs a known low temperature reference point for calibration and a thermostatically controlled cryoprobe such as those of the Spembly DFS 30 cryosurgical apparatus can be used. A layer of frost must be present to ensure correct emissivity or, better still, a small disc of the tissue under investigation can be placed over the tip. The whole probe tip will not be at one homogenous temperature so that it is necessariy to focus on one part, e.g. the periphery and check its temperature with an accurate thermocouple.

## APPARATUS AND RANGE

The Aga 680 and Aga 750 Portable apparatus have been used and found suitable for this work. The 750 is particularly useful in the clinic or operating theatre in view of its compact size.

The makers calibration curves [4] extend down to minus thirty degrees centigrade so that there is no problem in recording the important minus fifteen degree isotherm — we will call the area within this isotherm the « cell lethal zone » for convenience. Infra-red emission is generated by the motion of charged atomic particles in any material whose temperature is above absolute zero (0°K or - 273°) [5]. Our experiments (680) show that measureable emission certainly appears to occur down to as low as minus 100°C although much more work needs to be done on the values below minus 30°C. Fig. 1 shows the general outline of a calibration curve for subzero temperatures.

## VIEWING POSITIONS

Three basic camera positions relative to the probe (or other freezing source) have been found most useful (Fig. 2).

**1. Depth viewing** (Fig. 2 I). The probe P is positioned on a block of tissue T with its midpoint level with a perpendicular cut surface. The camera C views the cut surface allowing observation of the depth of freezing BB' within the iceball I. This is a useful method for use with nonvital tissue for in vitro comparison of the freezing characteristics of different probes or methods. With ingenuity it is possible to utilise depth viewing in living tissue in the experimental animal.

**2. Surface viewing** (Fig. 2 II). The camera is

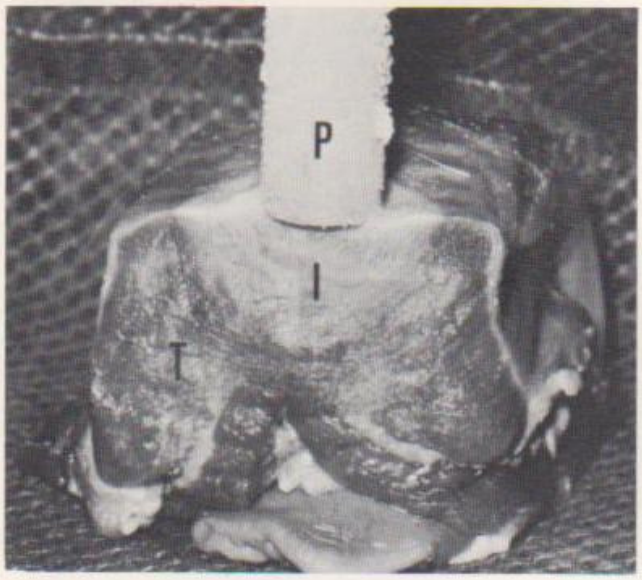


Fig. 3. DEPTH VIEWING position, showing probe (P), iceball (I), block of pig tongue tissue (T) in vitro.

positioned above the probe and views the outer surface of the tissue and lateral spread of the freezing process AA'. Camera positioning is aided by the use of a right angle configuration of probe so that the handle obstructs the camera's view to a minimal degree. This method is useful for in vivo monitoring of freezing particularly on skin or mucosal surfaces.

**3. Controlateral viewing** (Fig. 2 III). The camera is positioned on the far side of the tissue block to the probe and monitors penetration when it occurs in full depth CC'. This can be used clinically or experimentally during freezing of discreet tissue units such as a bone.

## RESULTS

Thermograms may be recorded in monochrome or colour. Monochrome allows clear deli-

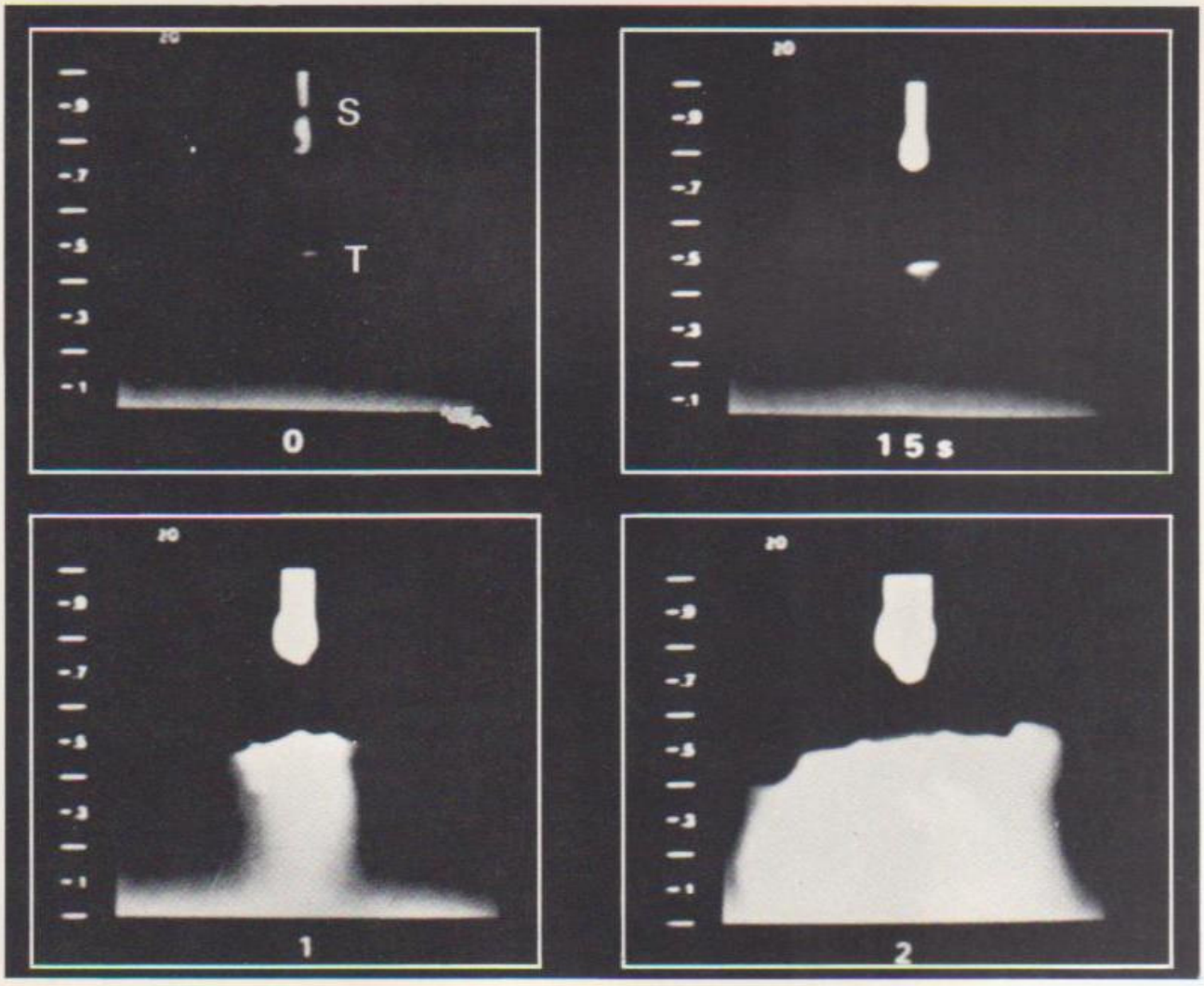


Fig. 4. Monochrome thermograms (inverted) of a liquid nitrogen spray (S) freezing tissue (T) in vitro (depth viewing position) at zero, 15 seconds, 1 minute and 2 minutes. Spray tip image increases in size due to icing up.

neation of the shape of the cryofront and individual isotherms. Colour is of great use for simultaneous recording of multiple isotherms. Results can be recorded photographically using a Polaroid attachment or single lens reflex.

## USES OF THERMOGRAPHY IN CRYOSURGERY

Experience has defined the following useful applications.

**1. Comparison of cryosurgical methods.** Freezing profiles for different apparati and individual probes can be demonstrated and compared in vitro and in vivo. This is especially useful in calcified tissues where thermocouple insertion is difficult.

Blocks of animal tissue can be used in vitro using the depth viewing position as shown in Fig. 3, or in vivo.

Fig. 4 shows a liquid nitrogen spray freezing a block of mucosa in vitro by the depth viewing position using monochrome. The level has been adjusted so that pure white is minus fifteen degrees Centigrade. The development of the cryofront with time can be followed.

Fig. 5, compares the performance of 3 different probes (A, inverted cone, B, tapered, C. cylindrical) and a liquid nitrogen spray (D) plotting the minus 15°C isotherm (« cell lethal zone »), and the minus 2°C isotherm (limits of observable ice ball) in each case. It can be seen that the configuration of the cryofront differs in each case. It is interesting to compare the

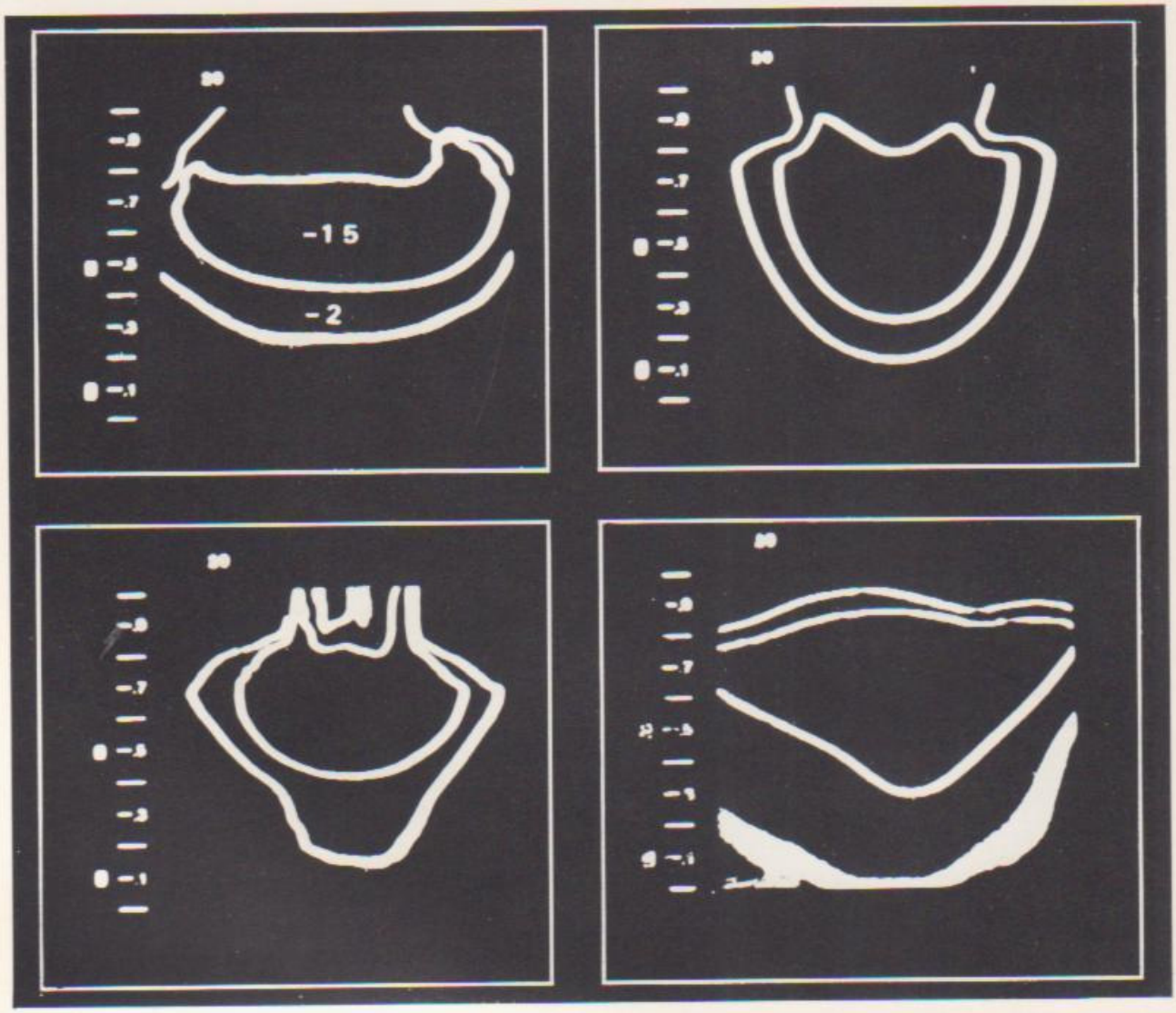


Fig. 5. Comparison of in vitro cryofronts of three different DFS 30 cryoprobes (A: inverted cone, B: tapered, C: cylindrical) and a liquid nitrogen spray (D) plotting — 15°C isotherm (« cell lethal zone ») and — 2°C isotherm (observable ice ball).

V shaped front for the liquid nitrogen spray with the convex fronts for the probes and to note that it has been achieved in half the time of the probes showing the remarkable potency of the spray which is repeatedly demonstrated using thermography. Fig. 6 shows a colour thermogram of a probe freezing a block of tissue in vivo (depth viewing). Multiple isotherms are simultaneously displayed. Fig. 7 shows contralateral viewing of freezing of a mandible in vitro and Fig. 8 the corresponding colour thermogram.

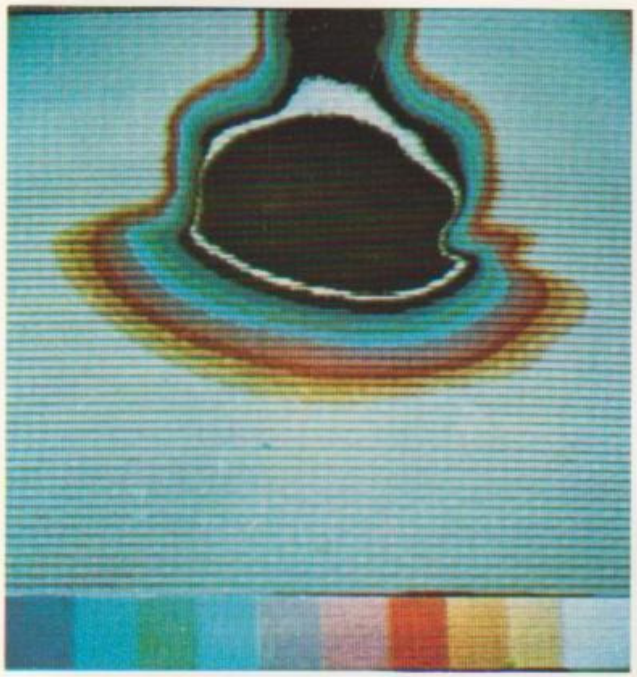

Fig. 6. Colour thermogram of an inverted cone probe freezing animal tissue in vivo. The assymetry of the cryofront is associated with tissue temperature gradients. The white isotherm defines the — 15°C « cell lethal zone ». Other isotherms can be calculated from calibration curves.

**2. Study of the effects of tissue temperature gradients.** It can be shown that tissue temperature gradients due to the heat sink effect of enclosed blood vessels modify the configuration of the cryofront (Fig. 6). Fig. 9A and B show the thermal outline of a blood vessel in a living pig's ear. Fig. 9C and D demonstrates how the presence of the blood vessel influences the configuration of a developing cryofront in the tissue (contralateral viewing).

**3. Clinical monitoring.** Work is being undertaken to establish methods of monitoring during clinical use. A preliminary thermogram of a lesion prior to cryosurgery allows an assessment of temperature gradients likely to influence the symmetry of the cryofront and may help in the accurate plotting of the treatment area [6]. Fig. 10 shows freezing a carcinomatous skin recurrence with liquid nitrogen spray.

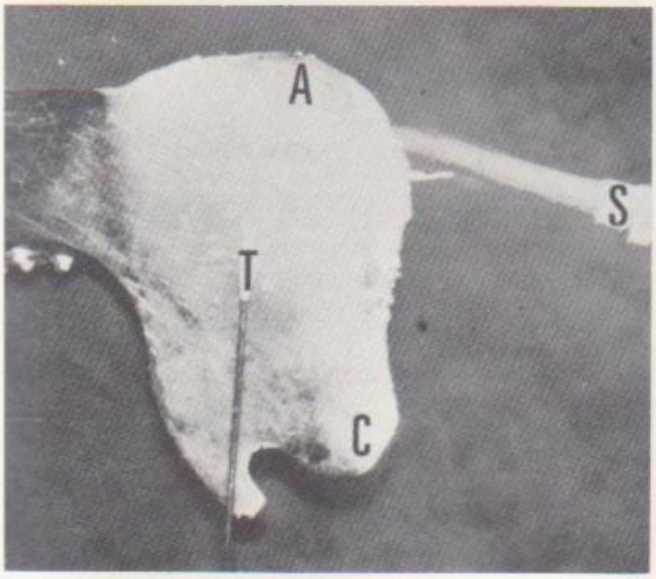


Fig. 7. Contralateral viewing position for pig mandible in vitro. Liquid nitrogen spray (S) is impinging on far side of bone (T: thermocouple checking results; A: angle of mandible; C: condyle).

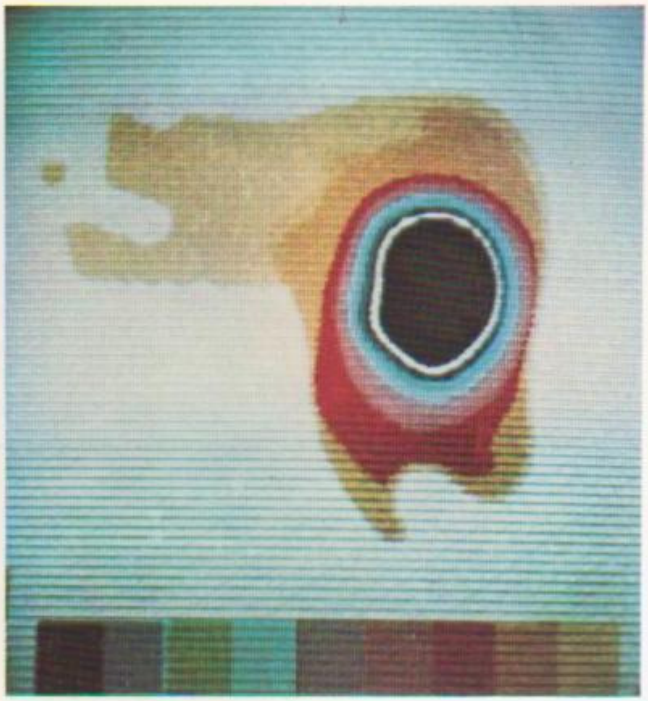

Fig. 8. Colour thermogram of type of experiment shown in Fig. 7. White outline defines — 15°C isotherm.

Fig. 11 is a colour thermogram of the established freeze (surface viewing). The white outline plots the — 15°C isotherm (« cell lethal zone ») so that it can be ensured that this encompasses the whole lesion under treatment. Fig. 12 shows the thawing pattern. Thermo-

**4. Early prediction of the zone of necrosis.** It may be possible to identify the area of cryonecrosis thermographically after a few days, by its temperature difference from surrounding tissue, without having to wait 2-3 weeks for sloughing to occur. It might then be possible to predict

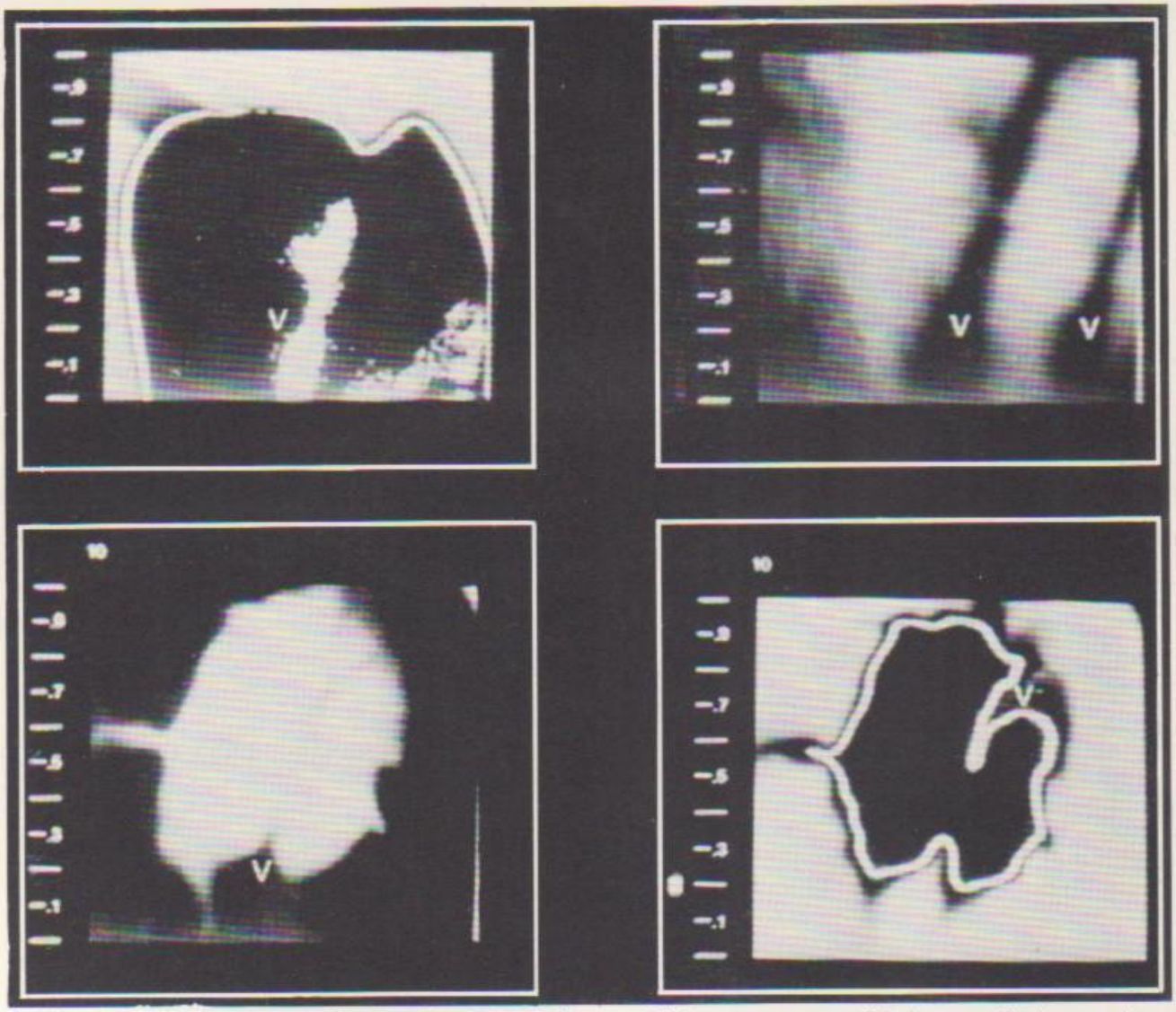


Fig. 9. Pigs ear preparation in vivo. A) isotherm picking out artery (V) in ear. B) inverted thermogram of vessels. C) outline of developing cryofront. Inverted thermogram. Contralateral viewing. D) isotherm plot of C) showing how heat sink effect of vessel modifies the cryofront outline.

grams can be stored in the patient's records for study retrospectively in the light of the clinical result. Such records could be likened to the radiotherapist's isodose diagrams. The information from surface viewing can be supplemented by readings from deeply placed multi-junctional thermocouples to form a three dimensional representation.

the need for further cryosurgery for a neoplasm without awaiting seperation of slough with a better chance of control. This is similar to the use of thermography to identify full thickness burns [7].

Fig. 13 shows a four day old cryolesion in a pig's cheek with localisation developing; Fig. 14 is a corresponding colour thermogram.

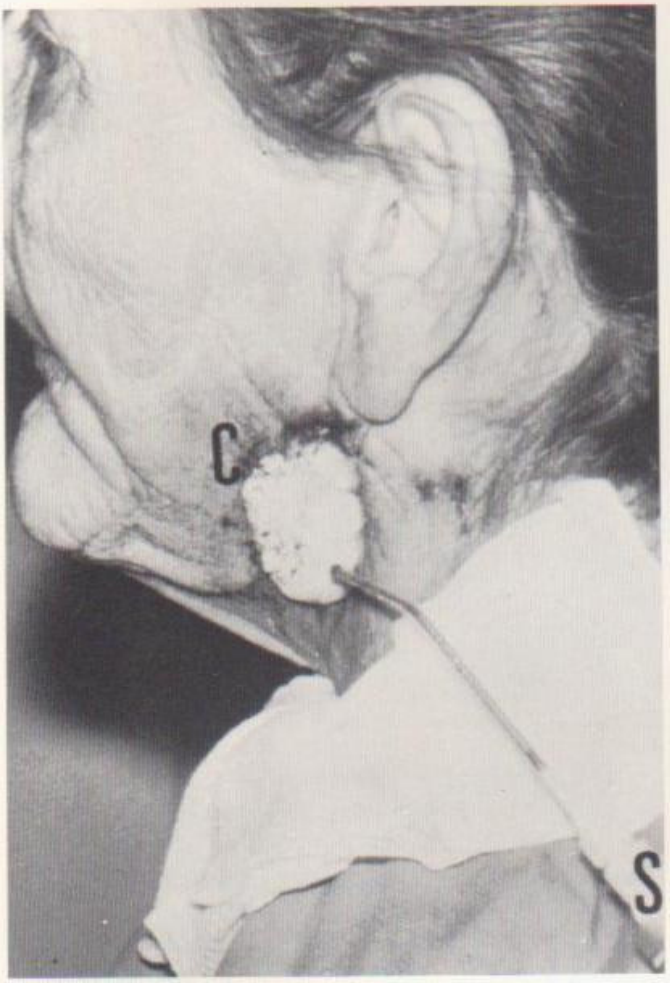


Fig. 10. Freezing a carcinomatous recurrence (C) in skin with a liquid nitrogen spray (S).

## CONCLUSION

Thermography could prove to play a useful part in a number of aspects of cryosurgical research, particularly in comparison of methods. Work is needed to verify further the reliability of results and to refine techniques. In clinical monitoring, thermography allows a photographic record to be obtained of the cryogenic process for later evaluation. Viewing at right angles can be a major problem in confined anatomical regions but reflection of infra-red emission by metallic mirrors could help to overcome this difficulty and initial experiments have been undertaken in this method. The non-linear relationship of temperature versus isotherm units at sub-zero temperatures is inconvenient but surmountable by the use of calibration curves, which however need further amplification in sub-zero values.

It would be of advantage to be able to plot temperatures down to the level of that of liquid nitrogen (— 198°C) but this would require more sensitive detector units. Errors from air currents etc. would be a real problem in detecting minute amounts of energy, probably requiring specialised experimental housing.

Thermography, on present evidence, shows promise of a significant role in cryosurgical research and merits further investigation.

Fig. 11. Surface viewing of procedure in Fig. 10, showing established freeze (— 15°C « cell lethal zone » outlined by white isotherm).

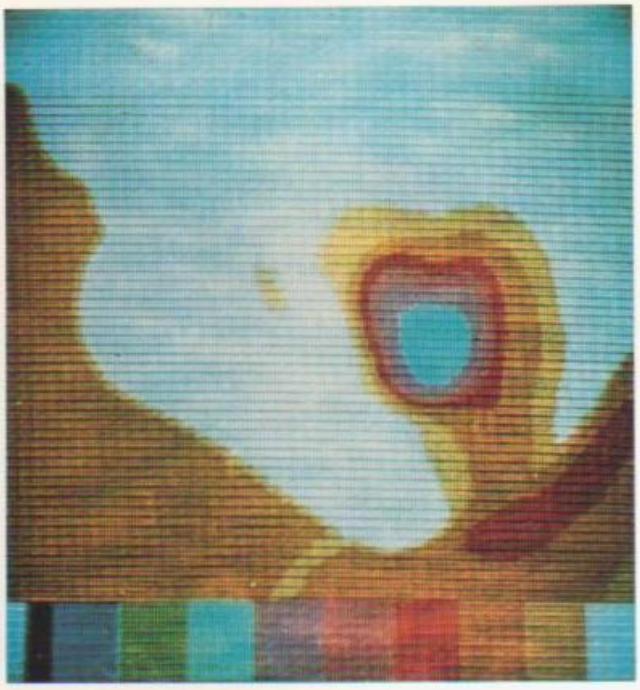

Fig. 12. Thawing pattern of procedure in Fig. 10 and 11.

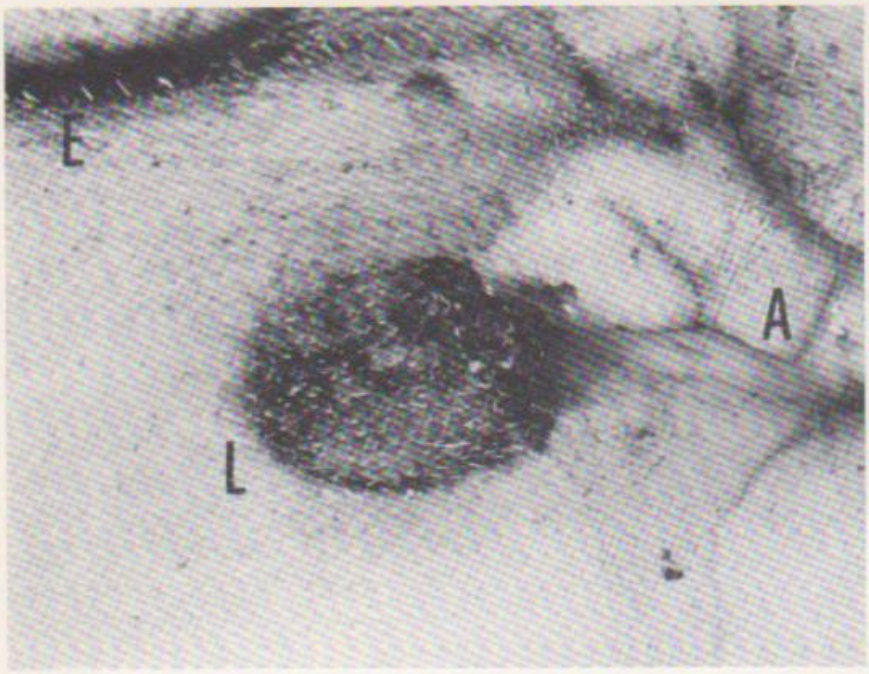


Fig. 13. Four day old cryolesion (L) in pigs cheek. (A: angle of mouth; E: eye).

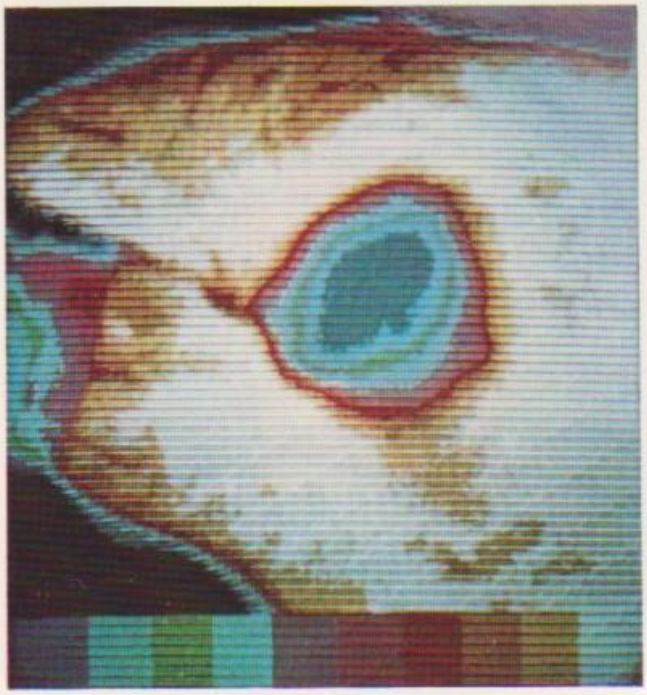

Fig. 14. Thermogram of situation in Fig. 13 showing localisation of infarct.

## REFERENCES


1. Gage A. A.: Cryosurgery for cancer. *Cryobiology*, **5**, 241-248, 1969.
2. Smith J. J., Fraser J.: An estimation of tissue damage and thermal history in the cryolesion. *Cryobiology*, **11**, 139-147, 1974.
3. Bradley P. F., Fisher A. D.: The cryosurgery of bone. An experimental and clinical assessment. *Brit. J. Oral Surg.*, **13**, 111-127, 1975.
4. Operating manuals for AGA 680 and 750. AGA infra red systems 518181 Lidingö, Sweden.
5. Park W. M., Reece B. L.: Fundamental aspects of medical thermography. British Institute of Radiology publication, London, 1976.
6. Amalric R., Spitalier J. M., Siegle J.: Dynamic telethermography as an aid in oncology for defining the treatment area I. Dynamic telethermography in clinical oncology 45-48. Sud-Régie, Asnieres, France, 1973.
7. Hackett M. E.: The use of thermography in the assessment of depth of burn and blood supply of flaps.: *Bru. J. Plast. Surg.*, **27**, 311-317, 1974.