enough energy for the daily needs. When an adequate diet is given at once with a sufficiency of insulin most patients are able to reduce the dose and a few give it up altogether for a time. The patient must be prepared to start insulin again as soon as sugar reappears, whether it is due to an illness or to some unknown cause, and if this is done promptly he may be able to give it up again. (2) In all patients under the age of 60, unless they are grossly over weight. (3) If the patient is over 60 and is thin. This is especially the case if the patient has had an acute onset with thirst and polyuria, no matter how old he is.

Dietetic treatment may be tried in all people who are grossly over weight. The disease in these cases has often started insidiously and been discovered in the course of a routine examination of the urine. If I decide to try the effect of diet alone I give a fast of one day's duration, and then increase the diet each day in the following way:

- Diet I.*—C. 30 gm., P. 61.6 gm., F. 74.2 gm.; 1,060 calories.
Diet II.—C. 45 gm., P. 64 gm., F. 74.5 gm.; 1,130 calories.
Diet III.—C. 60 gm., P. 66.4 gm., F. 74.8 gm.; 1,200 calories.
Diet IV.—C. 75 gm., P. 68.8 gm., F. 75.1 gm.; 1,270 calories.
Diet V.—C. 95 gm., P. 68.8 gm., F. 75.1 gm.; 1,322 calories.
Diet VI.—C. 110 gm., P. 72.3 gm., F. 85.7 gm.; 1,528 calories.

If a patient can take this amount of carbohydrate and maintain a normal blood sugar he does not need insulin, and may keep well for many years. I believe it is unwise to reduce the carbohydrate below 100 grammes. If the glycosuria returns when 100 grammes of carbohydrate is taken insulin should be started without delay and the carbohydrate of the diet increased to 130 grammes or more. If the patient is over weight he should lose weight, and if he does not the protein and fat of the diet should be reduced until the weight does decrease.

The amount of food in Diet VI is about the same as that of the maintenance diet, which can be calculated from a knowledge of the weight and height. Many workers think that this diet is less trying than the short fast, and believe that the glycosuria and hyperglycaemia disappear equally well.

Another variety of diet is that used by Newburgh and Marsh (1923), which differs from the other diets in that both the protein and the carbohydrate are kept very low, while the fat is high. This diet certainly worked very well before the introduction of insulin, but, with its low carbohydrate and protein, it is a trying one.

Embleton (1938) has had very good results with another kind of diet, containing about 140 grammes of carbohydrate, and he lays stress on the kinds of carbohydrate which should be used: he limits the amount in the form of starch to 60 grammes, with another 40 grammes of lactose in milk and 40 grammes in the form of fruit. The total protein is high, since 77 to 98 grammes is given as meat, eggs, and fish, together with another 36 grammes in the milk. He does not limit the amount of fat, and the caloric value is probably over 2,200. Embleton gives this type of diet to the patients with mild glycosuria, obesity, and high blood pressure, and has found that the glycosuria disappears, the blood pressure falls, and there is a reduction in weight. He has also found that the sugar-tolerance curve in this type of case will often return to normal. It will be observed that the diets which are used with success in this kind of diabetes vary considerably.

The type of diet, however, which should not be used is that in which the so-called diabetic foods are added. These increase the protein and fat intake very considerably, and are responsible for a great deal of ill-health in the elderly diabetic who is afraid to start insulin.

Treatment by diet alone should only be continued if it is meeting with success, as shown by the absence of glyco-

suria and ketones. If either or both of these are present persistently the general health will begin to suffer. Insulin should be started as soon as the glycosuria has reappeared, and the diet improved by the addition of extra carbohydrate. If this is done early the general condition in some patients may improve so much that insulin may only be needed for a short while.

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SULPHYDRYL COMPOUNDS AND WOUND REPAIR

BY

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Wounds, their causation, pathology, and management, are at the present time subjects of more than usual importance. Even in peacetime almost every hospital shelters patients—victims of trauma, burning, sepsis, or venous stasis—in whom epithelization is virtually at a standstill and in whom only the end-results of scarring and deformity can be anticipated. The economic importance of hastening healing, both to patient and to hospital, need hardly be emphasized.

In this paper an attempt is made to summarize our knowledge of the broad principles underlying wound healing (and especially of epithelization), with particular attention to the part played in this process by the sulphhydryl (—SH) radicle. Some of my preliminary work will be mentioned in the hope that it may form a basis for further experiment and research.

Broad Principles of Wound Repair

Of the four main types of tissue of which the animal organism is composed—nerve, muscle, connective tissue, and epithelium—only two, connective tissue and epithelium, show, in the mammalia at least, any marked powers of regeneration or repair. This they do by virtue of the fact that, given conditions where proliferation is required, such a cell can change from its normally fixed and differentiated form into one at the same time more simple and more mobile. Thus the elongated fibroblast can become similar to and perhaps identical with the macrophage; the surface epithelial cell ceases to form keratin and becomes amoeboid. "The epithelia of the mucous membranes in

the course of repair pass through stages similar to those just described in the case of the epidermis. Thus the columnar cells, ciliated cells, or squamous cells all become rounded, cilia are lost, and the cells become mobile. As repair proceeds the cells regain the characters of the mother-cells from which they originally developed. . . . Thus in the case of columnar ciliated epithelium the cells which go to form the new layer, from being spherical and mobile, become first fixed, then gradually columnar, and finally ciliated" (Gray, 1937).

Here, then, is the first broad principle of wound repair—the power in certain cells of temporary "modulation" from a fixed to a mobile form, so that actual transport of the cell from place to place can be effected.

An important difference exists, however, in the healing of small and large wounds. In the *small* wound, migration, both of epithelium and of underlying connective tissue, is all that is required; mitosis, if any, occurs after healing is complete, and then only as a compensatory mechanism around the fringes of the wound. In the *large* wound, however, whether caused primarily or by the breaking down by sepsis of the original wound, migration alone is insufficient. First the wound becomes filled with a temporary scaffolding of "granulation tissue" and, in the case of the covering epithelium, migration has to be eked out by cell division (Arey, 1932). The larger the wound the more important does growth by cell division become; and it is in such wounds that we are interested. In passing we may note that granulation tissue is merely a series of mushroom-like masses composed of blood vessels and young connective tissue, and that the longer this temporary tissue is needed before the covering epithelium is laid down the more gross will be the ultimate scarring as organization among the fibroblasts takes place.

The second principle, therefore, is that in small wounds cell migration alone can effect healing. In large wounds cell division is also required: the larger the wound the more important does this factor of growth by cell division become.

Mutual Interaction of Connective Tissue and Epithelium

We may next perhaps ask ourselves: "What, if any, are the mutual effects on one another of these two cell types—the epithelial and the mesenchymal?" The answer is still in dispute.

In tissue culture it is well known that both fibroblasts and epithelium grow readily in pure culture, migration and mitosis being often observed. On adding fibroblasts to a culture of epithelium, however, Drew (1923) noted what he called an "organizing effect" by the fibroblasts on the epithelium, the epithelial cells once more becoming differentiated and fixed.

Turning to the mutual interaction of these cells in tissue fragments, F. H. Bentley (1936), on the other hand, observing an upswEEPing of fibroblasts towards an overlying edge of proliferating epithelium at the margin of a wound, regarded this as a possible organizing effect, not by the fibrous tissue on the epithelium but by the epithelium on the underlying fibrous tissue. An extract prepared from the epithelium, however, failed to reproduce the characteristic pattern in the fibroblastic substrate. The converse experiment was not attempted. More recently Medawar (1938) has been able to prepare an extract (probably an aldehyde) which is a specific, reversible, and non-toxic inhibitor of mesenchyme. This when added to a mixed culture gives rise to a marked increase in the growth of the epithelium as the activity of the fibroblasts becomes depressed.

Though the evidence on both sides is copious and conflicting it would appear probable that the growth of

epithelium is opposed by that of adjacent fibroblasts, and that the depression of excessive fibroblastic activity would assist the more rapid epithelization of a wound.

The Essential Stimulus to Proliferation

It was Alexis Carrel (1924) who pointed out that the stimulus to proliferation in cells appeared to lie in the presence of dead and dying tissue around them, and, later, that embryo extract and the extract of leucocytes were particularly powerful in this respect. Tissue culture has perhaps over-emphasized this aspect of cellular life, for it is only by delayed-culture methods that the second phase—namely, differentiation—can be studied. There are, moreover, at least two distinct aspects of the undifferentiated phase which should be, but seldom are, regarded separately: first, the stage of amoeboid movement; and, secondly, growth by mitotic division. Cells grown in embryo extract exhibit both phenomena.

It was natural that the properties of embryo extract should soon be tested *in vivo* (Carnot and Terris, 1926; Nakumara, 1930), and I have personally confirmed the striking healing properties of chick-embryo extract in this respect. Unfortunately, however, embryo extract is not particularly easy to prepare and quickly loses its growth-promoting powers, so that from the therapeutic point of view it is impracticable. An attempt was made, therefore, to narrow down the actual formative stimulus, the first stage being its localization by Carrel and Baker (1926) in the higher split products of proteins. At a later date Baker (1929) found the presence of glutathione and haemoglobin together to have growth-promoting powers on fibroblasts *in vitro*.

It was in 1929, however, that Hammett (1929a, 1929b) and Hammett and Reimann (1929) first published their theory that growth by increase in cell numbers—i.e., by mitotic division—was dependent upon the presence of the sulphhydryl (–SH) radicle; and, further, that repair of a wound by mitotic division depended on the disturbed balance between reduced sulphur (–SH) and oxidized sulphur (S–S) being restored. A somewhat similar view was expressed by Rapkine (1930). In this view, therefore, wound repair represents a mass action between sulphhydryl (–SH) groups unmasked by the denaturation of the proteins from the injured tissues and the sulfoxide (S–S) groups into which they become rapidly converted; for –SH groups are themselves unstable and quickly break down. Further, as in any mass action, the products of the reaction—i.e., S–S groups—are themselves responsible for bringing the reaction to a standstill. Reduced to the simplest terms, therefore, –SH groups determine growth by mitosis: S–S groups, on the contrary, are the marks of differentiation. Again, it must be emphasized that the other important factor of growth—amoeboid movement—has not been mentioned.

Relation of Cell Stimulation and Cell Inhibition to the Genesis of Malignancy

If we are, at will, to bring about the abnormal behaviour of cells in the shape of acceleration and retardation of mitosis we must first exclude the possibility of unwanted side actions from these procedures.

Since malignant cells grow quickly, it has often been assumed that the stimulation of cells to a mitosis rate greater than normal might in itself have some bearing on the genesis of tumours. On close analysis, however, my own view is in accordance with that of Haddow (1938), who stated that "the local conditions which lead to tumour emergence are *not* such as primarily favour growth, but rather the reverse." In other words, the known carcinogenic agents (for example, small doses of

x rays over long periods; the carcinogenic hydrocarbons) are inhibitors of growth rather than anything else.

With this in mind I painted a number of mice with one of the hydrocarbons for a period of time short of producing tumours, and later placed wounds of a standard size in the areas of depilation. These wounds were therefore under the worst physiological conditions as regards tumour emergence. One-third of the animals were kept as controls, one-third of the wounds were treated with fresh embryo extract, and the rest of the wounds were dressed with heparin (as used in delayed-culture methods *in vitro*). Although one or two tumours arose in the controls, by far the greater number appeared in the heparinized—i.e., inhibited—wounds, and none at all in those treated with embryo extract. The latter, of course, healed the most rapidly. No wide conclusions can be drawn from such an experiment, but it is interesting to note that a similar anti-carcinogenic action when using a synthetic sulphhydryl compound together with one of the carcinogenic hydrocarbons has been recorded in America by Reimann and Hall (1936). In parenthesis, it may perhaps be remarked that although cells have been kept in tissue culture at an accelerated rate of mitosis for upwards of twenty years there has been no sign of a change in the direction of malignancy as tested by subsequent reimplantation of the cells into a suitable "host."

In the absence of wide evidence to the contrary, therefore, one feels that the physiological stimulation of cells to divide has no bearing in causing tumours and may possibly have the reverse effect. The deliberate inhibition of growth for long periods of time, on the other hand, should in the present state of our knowledge be treated with caution.

Clinical Aspects of Sulphydryl Therapy

It was naturally but a brief step from the identification of the sulphhydryl radicle and its association with mitotic division to its clinical application in the actual treatment of wounds.

Many compounds contain the -SH radicle, but not all are suitable for therapy. Glutathione (Brunsting and Simonsen, 1933), for example, though active, is ruled out on the grounds of expense alone. In this connexion, however, it may be noted that glutathione has been successfully used in the reactivation of tissue-culture media after mitosis had ceased (Verne and Verne-Soubiran, 1938). Following preliminary experiments in animals (Hammett and Reimann, 1929) and in man (Reimann and Hammett, 1929), Reimann (1930) obtained good results in a variety of wounds using a 1 in 10,000 solution of *p*-thiocresol as an intermittent dressing. Thioglucose, used previously, appeared to favour bacterial as well as tissue growth, and thiophenol tended to be too irritating. Thiocresol was chosen so that the cresol element might split off and act as an antiseptic. An ointment of approximately 0.5% thiocresol in lanolin (Reimann, 1931) was also effective not only in healing wounds but in thickening the skin of wounds which had been poorly covered. In 1932 Birnbaum reported the successful use of 1 in 10,000 thiocresol in burns and indolent ulcers, and as a dressing following skin grafting. These compounds, though not so expensive as glutathione, are still somewhat difficult to obtain. In 1933, however, Brunsting and Simonsen reported favourable results in 200 cases of cutaneous ulcer treated by means of a 0.5% solution of the sulphhydryl compound cysteine. Cysteine, in the form of its hydrochloride, is stable, though cysteine alone soon breaks down into the disulphide cystine. A fresh solution of cysteine was therefore made up each day (6.35 c.cm. of normal NaOH to 1 gramme of cysteine hydrochloride

in equal parts of saline and distilled water) and the dressing changed frequently. In the experimental field Owen (1937) found cysteine to be effective in accelerating the healing of radon necroses in guinea-pigs, such ulcers being particularly intractable to other forms of treatment. Other -SH compounds, such as methionine, (Toennies, 1937), have also been reviewed, and confirm the previous findings as regards their effect on growth by mitosis. Among the proprietary preparations merthiolate (Eli Lilly and Co.) contains a "thio" group as a mercuri-thiosalicylate.

My personal experience regarding the sulphhydryl series is something as follows. It is well known that, clinically, the ulcers of burns are "weak" ulcers in which healing is particularly sluggish. Feeling that this phenomenon might be due in part to coagulation of the proteins by heat in place of their normal slow breakdown (with unmasking of -SH groups) such as might follow trauma, it was decided to test the effect on such wounds of some of the compounds previously mentioned. Preliminary experiments in rabbits showed that cysteine hydrochloride (as a 0.5% ointment in lanolin) gave a 30 to 40% acceleration of healing, by measurement of surface area, in large excised wounds and a somewhat slower rate of healing in wounds caused by heat. In the case of burns the additional factor of malnutrition due to the resultant ischaemia may also be important. The 0.5% cysteine hydrochloride ointment was then tried out clinically on the skin "reactions" following deep x-ray or radium therapy, where often a good "control" wound was also present. In such indolent areas cysteine hydrochloride undoubtedly hastened healing and, used in a wound which is already granulating, is not painful. If the patient complains of pain, the cysteine may be made up fresh as a 0.5% solution in "buffered" alkaline phosphate or according to the method of Brunsting and Simonsen. Decubitus ulcers, burns, scalds, and traumatic epithelial defects also responded favourably to the ointment.

Conclusions

One feels therefore that the sulphhydryl compounds offer a new and definite approach, backed by experimental evidence, in the treatment of the large wound where healing is retarded. If, however, the additional factor present in embryo extract (which stimulates migration in addition to mitosis) could also be isolated an even more effective weapon might be in our hands. The possible dangers accompanying inhibition of fibroblastic activity, thus allowing of greater epithelial growth, yet have to be proved, and may or may not be real. It is more than likely that substances of the aldehyde class—e.g., propionaldehyde (Medawar, personal communication)—may eventually be found useful in such situations as the cornea and in plastic work, where even slight scarring is a matter of importance. In other situations the application above the dressing of wool and a firm bandage can do nothing but good, since Twyman (1922) has shown that epithelium will proliferate vigorously under pressures at which excessive fibroblastic growth is retarded. Used intelligently and in conjunction, therefore, all these factors regarding the physiology of tissue growth may be put to our advantage. It is for such reasons that this paper has been prepared.

Summary

The broad principles of wound healing have been outlined, emphasizing in particular that, although migration of cells alone is sufficient for the healing of the small wound, larger defects require the additional factor of growth by mitosis.

Epithelial growth is probably opposed by fibroblastic proliferation, but until our knowledge is increased deliberate cellular inhibition for long periods of time may be dangerous

as regards tumour formation. Physiological stimulation, on the other hand, would appear to be free from such dangers.

There is much evidence to show that compounds of the sulphhydryl (-SH) group tend to stimulate growth by mitosis.

Some clinical applications of sulphhydryl therapy have been mentioned, and a plea is made for their wider trial at the present time.

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THE RESPIRATOR AS AN OXYGEN APPARATUS

BY

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The importance of oxygen therapy in regard to war casualties is becoming increasingly appreciated. It is well recognized as being the most essential measure of treatment for gross anoxia, evidenced by cyanosis, resulting from injury to the respiratory apparatus from wounds, blast (Zuckerman, 1940; Falla, 1940), or gassing. It is also of considerable value as a supplementary measure of treatment in cases of shock from wounds or burns, though not of as great importance as transfusion of adequate quantities of blood or plasma. In shock the peripheral circulatory stagnation causes the blood to give up a very high proportion of its oxygen to the tissues and to return to the lungs abnormally depleted of oxygen. Inhalation of pure oxygen, as compared with air, significantly increases the amount of oxygen available to the tissues (Boothby, Mayo, and Lovelace, 1939; Wood, Mason, and Blalock, 1940).

If pure oxygen is to be given it is necessary to employ a face-piece apparatus. The B.L.B. mask (Boothby, Lovelace, and Bulbulian, 1938; Card, Forest Smith, Griffiths, McSwiney, and Savage, 1940) is probably the best. The nasal catheter method, even when used under conditions of maximal working efficiency (Marriott and Robson, 1936), is not capable of producing concentrations of oxygen much exceeding 50% in the inspired air, and is therefore not in general suitable for the acute oxygen lack of war casualties, though it has its place in the treatment of other conditions.

Converting the Respirator

When casualties occur in large numbers in a locality it is probable that there will not be enough efficient oxygen face-pieces available. The purpose of this note is to describe how the ordinary civilian or civilian duty types of respirator may be converted into makeshift oxygen masks permitting the administration of pure oxygen, the only piece of apparatus necessary to effect the conversion being an ordinary rubber football bladder (Association bladders,

size 4 or 5, will do). All civilians have such respirators, and practically all hospitals have stocks of spare ones.

Rubber football bladders are plentiful and cheap. The conversion from respirator to oxygen face-piece can be achieved within a minute, and involves no meddling with the construction of the respirator. The Service respirator is not so suitable for the method of adaptation to be suggested because its inlet valve is situated in the canister instead of in the face-piece, and an attempt at conversion would necessitate detachment of the wired-on rubber hosing.

A hole is made in the pole of the football bladder remote from the inlet by simply cutting off the terminal inch of the deflated folded bladder. This hole is then stretched and slipped over the canister (see illustration)

for a distance of three-quarters of an inch—if the hole is of the right size it should result in the canister being firmly gripped by the bladder. The gas-tightness of the junction should be reinforced by moving forward the rubber band which secures the face-piece to the canister (this junction can take care of itself as a rule) or else by using another rubber band. The presence of a "context" attachment does not matter; it should be regarded as part of the canister.

The Apparatus in Use

The inlet tube of the football bladder should be connected direct to tubing from the oxygen cylinder. It is not necessary to interpose a flowmeter or a humidifier. The oxygen should be turned on before the face-piece is put on the patient. When it has been put on the flow should be regulated so that the bladder is moderately generally distended during expiration, and does not empty completely even at the end of inspiration—it should be half collapsed at this point. To keep it distended both during inspiration and expiration necessitates an extravagant flow; to allow it to collapse completely during or at the end of inspiration is to be giving an inadequate flow and to make the patient suffocate. When the flow is nicely adjusted in accordance with the above instructions it is likely with a man at rest to be about 6 to 8 litres per minute. With a patient making respiratory efforts it may need to be more. If the patient cannot be kept under constant observation it is desirable that the adjustment of flow should err on the side of liberality and that the bag should only collapse slightly towards the end of inspiration. No unconscious patient or one too weak to remove the mask himself should ever be left unobserved when receiving oxygen by a face-piece which covers both nose and mouth. To this rule the converted respirator is no exception.

The valve in the face-piece prevents rebreathing into the bladder. The bladder performs four important functions: (1) It provides a simple method of connecting the oxygen supply to the face-piece. (2) Because of its collapsible nature it forms an indicator for the adjustment of the rate of flow as described above. (3) It economizes oxygen by allowing it to accumulate during the expiratory phase of respiration, which occupies about two-thirds of