# THE WATER RETENTION COEFFICIENT OF SURGICAL DRESSINGS

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Received July 1, 1952.

## INTRODUCTION

ONE of the most important properties of an absorbent surgical dressing is its ability to absorb water, médicaments or secretions. There are two factors which contribute to the successful function of the dressing for this purpose. One is the speed with which the liquid soaks into the dressing, for if this is too slow, the liquid may fail to penetrate in the comparatively limited time which may be all that is available. This is the property usually called "absorbency" and is measured, for example, by the sinking test of the British Pharmaceutical Codex. It is, without doubt, dependent on the physical chemistry of the surface of the fibres, and has been studied by one of us (Savage[1]). The other property, with which this paper is alone concerned, is often confused with absorbency, but it is in reality quite different, for it determines, not the speed at which the liquid is absorbed, but the maximum quantity which it can absorb. It is important because on its magnitude depends, for example, the time for which a dressing of a certain size absorbing a secretion can be left in position, or the quantity of blood which can be taken up by a swab of a given size, or the quantity of a medicinal liquid which can be applied by a swab which is soaked in it. It is widely known, in a vague way, that sphagnum moss possesses this property in high degree (Martindale[2]), and that cotton wool is better than gauze for this particular purpose. An attempt was made by the British Government to specify the property in sanitary towels for the women's forces during the war, and the Belgian Pharmacopœia 4th Edition, 1st Supplement, 1940, p. 76, includes a test for it in the monograph on cotton wool, but we believe that a detailed examination of a number of dressings under a range of pressures has not been published before, and that, although many of our conclusions confirm informed opinions on this subject, some will be found to be new.

## THEORETICAL

Although a dressing used to absorb secretion is often renewed before it is saturated, it seems likely that even in this case, there is a rough proportionality between the amount absorbed at the time when it is deemed advisable to renew the dressing and the amount required completely to saturate it. In other cases the dressing is actually allowed to become fully saturated before it is discarded. It seems therefore that it is the maximum quantity of liquid absorbed that is of interest. When dressings are wetted, they always collapse to a certain extent. Under conditions of practical use, there is often a further decrease of volume, because there is some external pressure, such as that of a bandage, or the pressure exerted by packing into a body cavity. No dressing can absorb more liquid than its own volume in this final condition minus the volume of the fibres themselves. The volume of the fibres is usually very small in comparison with the volume of the dressing, so that we can state the principle, at the risk of inviting criticism for making an obvious statement, that the maximum absorbing capacity of a dressing is its own final volume under the working pressure. Unless the working pressure be defined, the volume is indeterminate, and comparisons are almost impossible. This is the weakness of methods of measurement depending on soaking a dressing and then allowing it to drain for a certain length of time. Not only is the end-point difficult to define, but the load is the minimum likely to be experienced in practice (although it does apply to swabs) and the results may be very different when practical loads greater than these are applied. Mention must be made of another method of determining a property which at first sight seems related to that under discussion. The British Cotton Industry Research Association developed a test for another purpose, in which weighed quantities of material were wetted, and then spun in a centrifuge. The quantity of water left on the fibres was measured. At the end of this experiment the water is retained on the fibres as a thin film, the main spaces between the fibres being filled with air. This is not at all what happens in a saturated dressing under pressure, where the liquid fills all, or almost all the spaces between the fibres, and we think that the centrifuge test is usually inapplicable as a measure of the efficiency of a surgical dressing.

It is interesting to consider the forces involved in the absorption and expulsion of the liquid. Liquids enter such materials by capillarity. The laws involved in this are well known, and have been discussed in their application to this particular problem in the paper already cited (Savage[1]). Clearly the expulsion of water may involve, under certain conditions, a mere reversal of this process, and when dressings drain under gravity, suction or a centrifugal force, capillarity may be the dominant factor. But the changes in dimensions of the dressings are not considered on this simple theory.

When water soaks into a dry dressing the latter tends to collapse. The forces involved in this process appear to be: (*a*) at the beginning, the surface tension of the films of water extending from one fibre to another; and (*b*) at the end, the surface tension of the whole exterior water surface, when the completely saturated dressing is considered as a mere support for the volume of water retained by the dressing; and (*c*) the weight of the water, hanging, so to speak, from the upper surface of the dressing. Opposing these forces is the mechanical rigidity of the fibres, and equilibrium is obtained when this balances the sum of the other three.

We have considered whether viscosity plays any important part in the process. At very high pressures there can be little doubt that, since the passage of liquid through narrow spaces is involved, viscosity must enter into the total conditions, but a characteristic of the expulsion of water from dressings under pressure either in practice or in our apparatus, is that the expulsion is rapid but ceases almost at once when the pressure is held constant. This is not the way a liquid behaves when its flow is mainly determined by its viscosity. It would then be expected that compression would be strongly resisted by any sudden application of force, but if the force were maintained at a steady value, the liquid would continue to flow until the dressing had completely collapsed. We think therefore that viscosity cannot be involved to any large extent. It can now be seen that the elastic properties of the fibres and their arrangement in the dressing are important features, for it is the elasticity of the fibres which resists the complete collapse of the dressing under its load.

It will be shown in a later section that our results can be expressed by a simple mathematical transformation into the form of a rectilinear equation. In spite of what might thus appear to be a manifestation of a simple physical law, we consider that it is merely an empirical relation, and that the whole process is complicated, with the various forces exerting influences which are not in the same proportions at various phases of the process. For example, when pressure is first applied to a dressing the fibres are well separated and it seems reasonable to suppose that they act as an assembly of springs, and so Hooke's law, that strain is proportional to stress, should be followed. As pressure is applied, the fibres pack more tightly, and friction effects enter into the process. It would be expected therefore that the stress required to produce a given strain would increase. Later still, the fibres may come into closer contact, and perhaps lock with one another and a further increase in the force required to compress the dressing is to be expected. Since none of these additional effects begin suddenly at any particular pressure, it would be expected that on plotting stress against strain, a curve would be obtained in which the slope of the portion representing the events at low pressure is that due to Hooke's law and that as pressure increases the slope would decrease gradually. This is just what we find.

It must be noted that the processes are not reversible—a wetted dressing, particularly of cotton wool and similar materials, does not regain its original volume after the water has been expelled by pressure and the pressure has been removed, or even when it is dried. It can easily be understood that the expansion of a wet dressing in air would involve the extension of films of water between one fibre and another. The energy needed for this expansion is no doubt one cause of the failure of the wet dressing to expand, but the failure of the dressing to expand when it is dried must presumably be due to an irreversible rearrangement of fibre orientation—the fibres may perhaps coil round each other in a new way when wetted, and not be able to uncoil when dried, until mechanical work, such as teasing or carding, is done on the material.

We have not carried our theoretical analysis further than this brief account, but we feel that the interpretation of the practical experiments described below may be helped by providing a simple physical picture, however incomplete, of the events which probably occur when a dressing is in use. We have replaced the term "absorbing capacity" by the term "water retention coefficient" in order to avoid confusion with "absorbency." We define water retention coefficient (W.R.C.) as the number of g. of water absorbed per g. of dressing.

Before the laboratory work on this subject commenced it seemed essential that the pressures likely to be encountered in practice should be investigated, and J. R. Elliott undertook to carry out tests. In Part I of this paper the laboratory experiments are described, and are mainly by two of us (R.M.S. and D.M.B.), although certain results have been taken into this part from Mr. Elliott's work. Part II of the paper describes the methods and results of the experiments on the actual pressure found in bandaging. The two parts are therefore complementary, and it was very convenient to present these as a single paper.

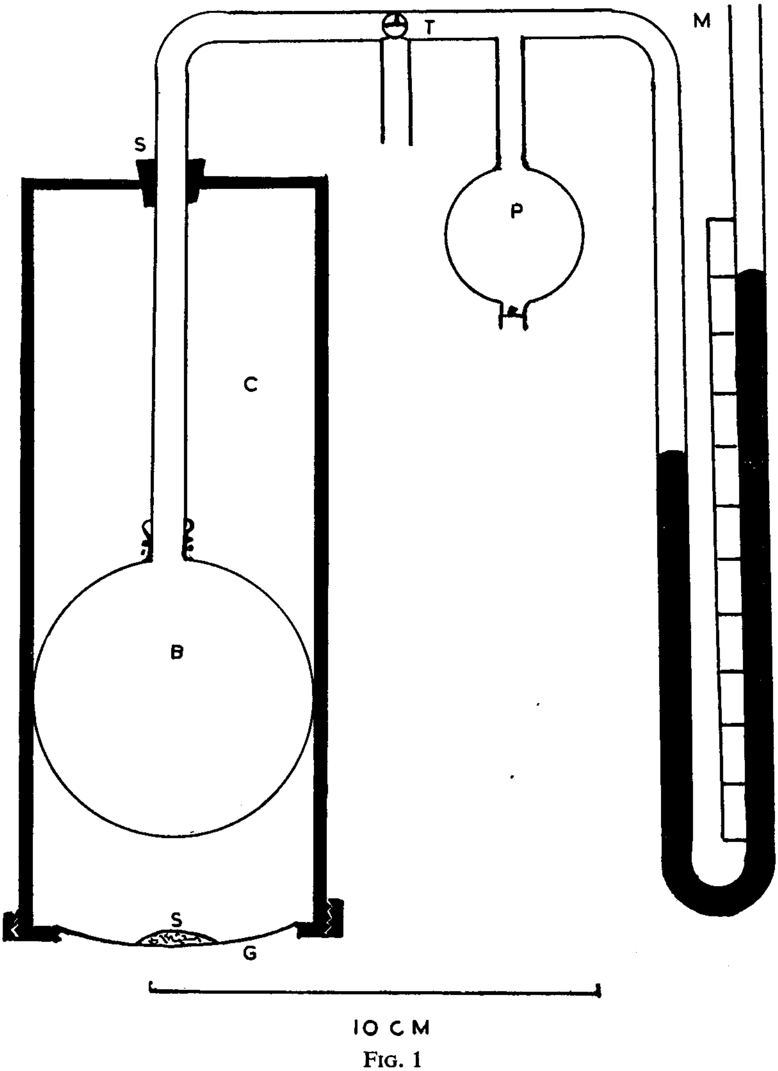

FIG. 1

## PART I LABORATORY EXPERIMENTS

*Experimental.*—The nature of the apparatus used will be evident from Figure 1. Essentially, uniform pressure is applied to a sample of the dressing S supported on bandage cloth G, by inflation of a rubber balloon B enclosed in an aluminium cylinder C. The pressure in the balloon is measured by a mercury manometer M. Determinations were made as follows. The weighed sample was placed in position on its support and both sample and bandage cloth were thoroughly saturated with water. It was then placed in position at the base of the cylinder and the balloon was inflated with a hand pump P to the required pressure.

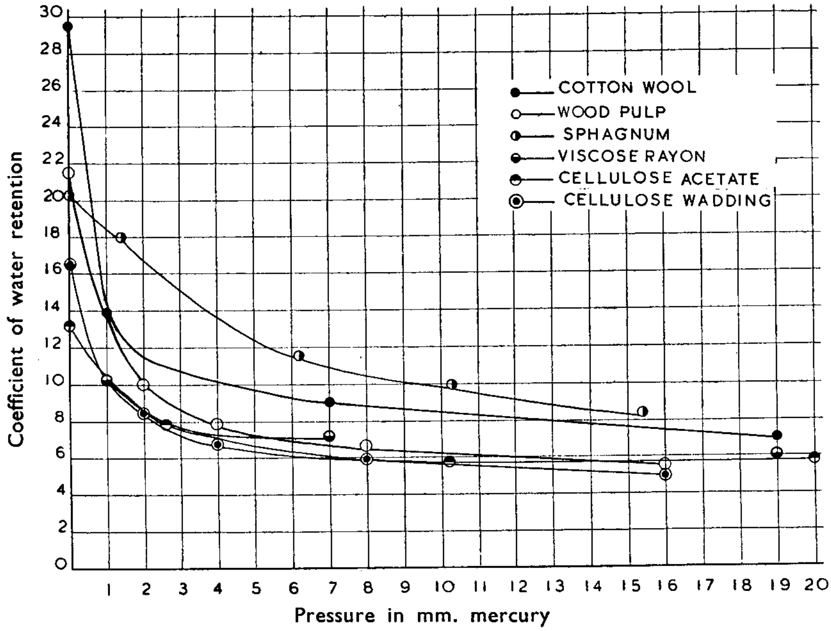

FIG. 2. Non-woven dressings.

Water ran out of the dressing until the maximum pressure was reached and fractional drops hanging beneath the support were adroitly removed with filter paper. The air pressure was then released and the sample removed and weighed. Experiments were made to determine the pressure required to inflate the balloon to the point where good contact was made between balloon and the supporting gauze. This pressure was considered the zero value, and the actual manometer readings were corrected by subtracting this value. This procedure would not be correct if the volume changes in the balloon were large after the zero value had been reached, but the pieces of dressing used were quite small (about 0·25 g.) and we consider that the much larger balloon was so little altered in size during the experiments that this procedure was justifiable.

The apparatus gave sharp readings—there was no delayed drip and the results were reproducible. It also appears to be reasonably close imitation of practical conditions for dressings are often compressed under bandages against yielding tissues. We considered that methods depending on the use of rigid compression devices were undesirable, for in such cases, the load might be carried largely by an accidentally dense part of the dressing and might then give rise to an abnormally high water retention coefficient. The results are shown in Tables I, II and III and in Figures 2, 3 and 4.

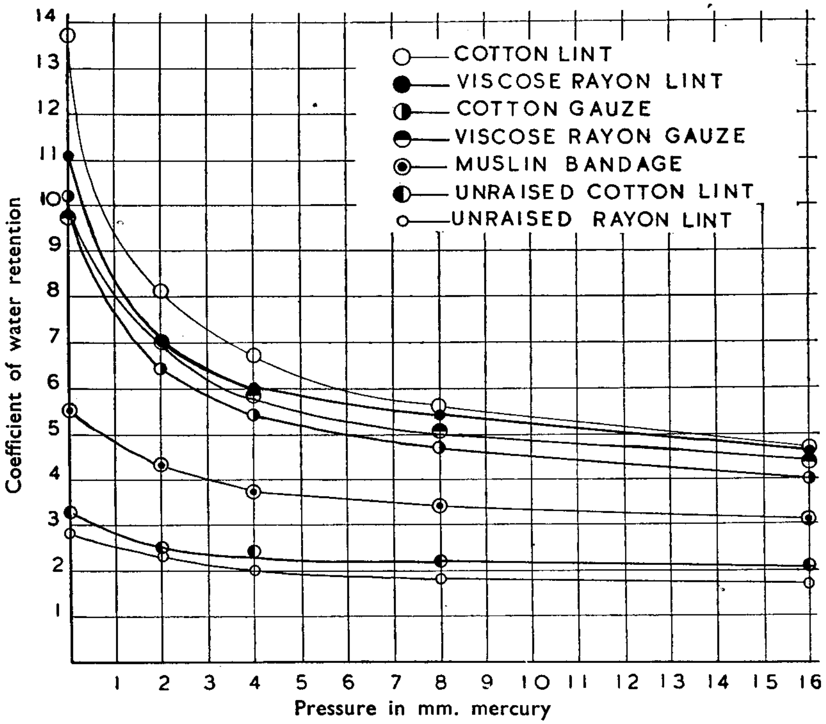

FIG. 3. Woven dressings.

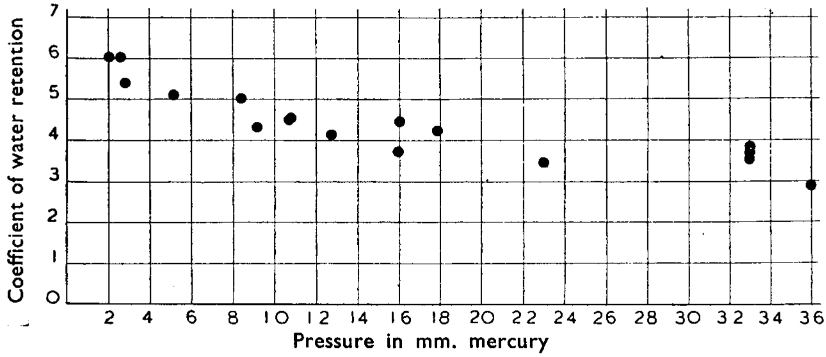

FIG. 4. Lint, scatter diagram.

TABLE I

PRESSURE (CM. HG)

| Material | 0 | 1 | 2 | 4 | 7 | 8 | 16 | 19 | Regression‡ |
|---|---|---|---|---|---|---|---|---|---|
| Gauze, 19 × 10* .. .. | 9·7 | | 6·3 | 5·4 | | 4·6 | 4·0 | | 0·87–0·22x |
| „ B.P.C.* .. .. | 10·2 | | 6·4 | 5·4 | | 4·7 | 4·0 | | 0·87–0·23x |
| „ 12 × 8* .. .. | 10·8 | | 7·4 | 6·1 | | 5·3 | 4·5 | | 0·94–0·24x |
| „ viscose rayon 19 × 15* | 9·9 | | 7·0 | 5·9 | | 5·1 | 4·4 | | 0·92–0·23x |
| Muslin Bandage B.P.C.† .. | 5·5 | | 4·3 | 3·7 | | 3·4 | 3·1 | | 0·67–0·16x |
| Lint, B.P.C. .. .. .. | 13·7 | | 8·1 | 6·7 | | 5·6 | 4·7 | | 0·99–0·27x |
| „ viscose rayon .. .. | 11·1 | | 7·0 | 6·0 | | 5·4 | 4·6 | | 0·90–0·20x |
| „ cotton, unraised.. .. | 3·3 | | 2·5 | 2·4 | | 2·2 | 2·1 | | 0·42–0·08x |
| „ viscose rayon, unraised .. | 2·8 | | 2·3 | 2·0 | | 1·8 | 1·7 | | 0·39–0·13x |
| Cotton wool, hospital.. .. | 33·0 | | 12·5 | 9·9 | | 8·6 | 7·4 | | 1·15–0·24x |
| „ „ B.P.C. *a* .. | 33·0 | | 12·4 | 9·8 | | 8·3 | 7·2 | | 1·16–0·25x |
| „ „ B.P.C. *b* .. | 29·5 | 13·9 | | | 9·0 | | | 7·0 | 1·14–0·23x |
| Wool, viscose rayon .. .. | 16·5 | 10·6 | | | 7·7 | | | 6·2 | 1·02–0·18x |
| „ towel .. .. .. | 24·0 | | 10·9 | 8·5 | | 7·3 | 6·3 | | 1·11–0·26x |
| Wadding, cellulose .. .. | 16·5 | | 8·4 | 6·7 | | 5·8 | 4·9 | | 1·00–0·26x |
| Wood-pulp, sulphite .. .. | 21·7 | | 10·0 | 7·8 | | 6·6 | 5·5 | | 1·08–0·28x |

* 16 Layers. † 8 Layers.

‡ Log W.R.C. = a – bx where a and b are the constants shown in this column, and x is log pressure in cm. of Hg.

In all cases the points represent the means of at least 4 independent readings. In Figure 3 the range of individual readings in the course of a single experiment is shown for lint B.P.C.

The experiments in Table II, however, carried out by J. R. Elliott, were performed in a rigid apparatus, and produced similar results. It is possible that the depth of cotton used in his experiments was sufficient to produce an averaging effect, so that the effective pressure was more uniform than would show in a thin layer. His method is as follows: 2 g. of the cotton wool was packed into a cylindrical tube with a perforated base plate of about 2·5 cm. diameter, so that it occupied a volume of about 15 ml. It was thoroughly saturated with water and then subjected to a given load, applied from above by means of brass weights. After 5 minutes, no further water was being squeezed out from the sample, and it was then carefully removed from the tube and weighed. Further samples were subjected to different loads, and the whole series repeated using a rayon wool (see Table II).

*Discussion.*—The wide difference between different kinds of dressings is at once evident. Cotton and rayon wool are, on this basis in which equal weights of dressing are compared, much better than the woven

TABLE II

SHOWING THE QUANTITY OF WATER RETAINED BY 2 G. OF COTTON WOOL B.P.C. AND RAYON WOOL UNDER DIFFERENT PRESSURES

| Load applied in g. per sq. cm. | Water retained by 2 g. of sample | | Approx. ratio of water retained cotton/rayon |
|---|---|---|---|
| | B.P.C. cotton wool | 100 per cent. rayon wool | |
| 15·8 | 27·9, 26·5 | 22·4, 22·9 | 1·20 |
| 18·8 | Not taken | 21·1, 22·0 | — |
| 24·0 | 24·2, 24·5, 24·0 | 20·4, 20·1 | 1·19 |
| 31·6 | 22·8, 22·5, 22·8 | 19·1, 19·3, 20·2, 19·3 | 1·15 |
| 39·2 | 21·4 | 18·3 | 1·17 |
| 46·8 | 20·3, 20·5, 21·8 | 17·3, 17·0, 17·5 | 1·20 |
| 64·0 | 18·0 | 15·0 | 1·20 |

form of surgical dressing, although sphagnum is still better (Table III). Then follow paper pulp and cellulose wadding.

Lint comes next, followed by the open gauzes, B.P.C. and hospital qualities, that are commonly used in Britain. The finer gauzes, in use in most other countries are not so good.

This is an interesting point because since these open gauzes are almost always used in portions several layers thick, it could easily have been supposed that fewer layers of a closer cloth would be as good or even better. The British practice, however, is now seen to be the best.

TABLE III

SPHAGNUM (CAPITULA)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pressure (cm. Hg) .. .. .. .. | 0 | 1·4 | 6·2 | 10·3 | 15·4 | 25·5 | 36·0 |
| Water retention coefficient .. | 22 | 18·0 | 11·5 | 9·9 | 8·3 | 7·1 | 6·4 |

In cotton wool we have not found that quality makes any difference to the water retention coefficient. B.P.C. cotton wool behaves in the same way as a sample so poor in other respects that it could not have been used as a dressing. It is different with lint. Poorly raised material has a lower water retention coefficient, and unraised is much inferior, although the cloth is otherwise identical. Lint is another dressing almost peculiar to British countries, and it is interesting to find that no other woven fabric equals it in water retention coefficient. We have considered the reason for these results, and suggest that a high water retention coefficient is associated with disorder in the arrangement of the fibres. In cotton wool the fibres are not parallel and are curled. In rayon wool the fibres are straighter, and the degree of order is higher. Woven fabrics have the fibres much more parallel. In lint, disorder is deliberately introduced by the raising process and with the increase in disorder goes an increase in water retention coefficient, for unraised lint is considerably inferior to raised lint, poorly raised lint is intermediate. Paper pulp, the disintegrated and disorientated raw material of cellulose wadding, has a higher water retention coefficient than cellulose wadding, in which the fibres are laid layer on layer in a more orderly manner. A multiple layer of coarsely woven gauze is a more disorderly arrangement than a single layer of a closely woven fabric, and the water retention coefficient is higher in the multiple layer dressing.

So far, we have considered the results calculated on a weight/weight basis. This is the only way in which precise figures can be stated, for the volume of a dressing is an indefinite quantity, and depends on the load upon it and upon its previous history. But some consideration must be given to the efficiency of dressings judged by the capacity of a given *volume* of dressing to absorb liquid for there are important uses where the quantity of dressing which can be used is limited by the volume. For example, a cavity or space in or on the body may limit the amount of dressing which can be applied, or a soldier's pocket or a first-aid outfit may be of limited size, and we must know what the most efficient kind of dressing would be under these conditions. Clearly the required figure can be obtained by multiplying the water retention coefficient by the apparent density of the dressing, and in Table IV we show some results. The difficulty in presenting these results has been to choose a figure for the apparent density. We have taken that which is found in commercial packages. We think that this is as good a guide as any, but it must be realised that to get a true value for any particular case, the actual apparent density should be determined under working conditions, and used in the calculation.

TABLE IV

| | Water retention coefficient at 2 cm. Hg. | Apparent density g./ml. | Volumetric water retention coefficient |
|---|---|---|---|
| Cotton wool .. .. .. .. | 12·5 | 0·16 | 2·0 |
| B.P.C. cotton gauze .. .. .. | 6·4 | 0·26 | 1·7 |
| Cotton lint .. .. .. .. | 8·1 | 0·31 | 2·5 |

Table IV shows that in these representative kinds of dressing when volumes are considered, gauze gains considerably in its efficiency when compared with cotton wool, but is still not so efficient. Lint, however, from being second to cotton wool when compared on a weight/weight basis takes first place on a volumetric basis.

*Surface-active agents.*—Some experiments were made in which a commercial detergent was added to the water. The results (Table V) show that the water retention coefficient is diminished; this is to be expected for there can be no doubt that the surface tension of the liquid is the factor retaining it in the dressing. The particular interest, however, lies in the clear demonstration of the independence of the water retention coefficient and absorbency, for measures which would increase the rate of wetting decrease the quantity retained by a fully saturated dressing.

TABLE V

EFFECT OF SURFACE-ACTIVE AGENT ON WATER RETENTION COEFFICIENT OF VISCOSE RAYON WOOL

| | | | |
|---|---|---|---|
| Pressure (cm. Hg) .. .. .. .. | 2·6 | 10·2 | 25·5 |
| Water retention coefficient .. .. .. | 9·7 | 6·7 | 5·3 |
| Water retention coefficient in presence of surface-active agent .. .. .. | 8·0 | 5·4 | 4·1 |

*The absorption of blood.*—The use of a complex fluid such as blood containing suspended solids introduces complications, and although the relation between the water retention coefficient and the corresponding values obtained by using blood or pathological fluids would be of much interest, the matter was felt to be too large for inclusion in a study which is not exhaustive. One series of experiments was made, using sulphated blood and showed that blood is retained by a dressing in larger quantities than is water under similar pressures.

*Mathematical considerations.*—By plotting the logarithm of the pressure against the logarithm of the water retention co-efficient, it was found that the points fell approximately on straight lines. Regression equations were calculated (Table I) for the materials. Tests for rectilinearity were applied and in many cases it was found that there was no significant departure from the expected values, but in other cases there were signs that the points followed a slightly sigmoid curve. It is unlikely that the equations indicate any fundamental mathematical law in our results, but there are two advantages in this method of expression—it is sufficient to determine the water retention coefficient at only two pressures in order to characterise the dressing completely either graphically by drawing in the line between the points or numerically by the two constants of the equation, whose physical meanings are (*a*) the quantity of water retained under unit load and (*b*) the rate at which this quantity diminishes as the load is increased. These constants could be incorporated in any description of a dressing, or used in a specification.

## PART II

*The pressure exerted by bandages on absorbent dressings.*—A limited series of experiments was undertaken in the first instance to investigate the variation in pressure obtained when one worker bandaged a forearm, on a number of occasions, using a fast-edge, open wove, bandage, 2 inches wide, under as nearly the same conditions as possible to produce a comfortable dressing.

The apparatus used consisted of a water manometer, graduated at 1-cm. intervals, to one limb of which was attached a length of pressure tubing, and at the end of this tubing a soft rubber bag was attached by means of rubber solution. The end of the tube with the rubber bag was then loosely tied along the limb to the bandages and the bandage applied in such a way that it commenced about 2 inches below and finished about 2 inches beyond the bag.

TABLE VI

PRESSURES EXERTED ON A BARE FOREARM, BY A WHITE OPEN WOVE (FAST EDGE) 2 INCH BANDAGE, THE ARM BEING RESTED AND RELAXED

| Number of bandage | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure when applied . . | 39½ | 37½ | 33½ | 28 | 37 | 29½ | 35½ | 25½ | 33 | 32 | 26½ | 23 | 31¾ g./sq. cm. |
| Pressure after 10 minutes | 34 | 33 | 30 | 24 | 33 | 24 | 32 | 22 | 28½ | 25 | 24 | 20½ | 27½ ,, |
| Fall in pressure . . . . | 5½ | 4½ | 3½ | 4 | 4 | 5½ | 3½ | 3½ | 4½ | 7 | 2½ | 2½ | 4¼ ,, |

It was found that during the first few minutes after application of the bandage the pressure dropped to a noticeable extent (Table VI) presumably due to the fabric settling down around the limb, and so, in subsequent experiments, pressures were not compared until the bandage had been in place for 10 minutes.

In order to obtain as much information as possible, after the bandage was applied the subject was instructed to hold his arm in 4 different positions, namely: (1) seated, with arm loosely supported at the wrist by a second person; (2) standing, with arm held loosely by the side; (3) standing, with arm held horizontal as in a sling; (4) arm extended and fingers widely stretched apart. 4 sets of readings were taken in each position and averaged for each bandage (Table VII).

## TABLE VII

PRESSURES EXERTED ON BARE FOREARM, BY A 2 INCH WHITE OPEN WOVE (FAST EDGE) BANDAGE, AFTER BEING ALLOWED TO SETTLE FOR TEN MINUTES

Each figure represents an average of four readings
All readings are cm. of water

| No. of bandage | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Seated, arm rested .. | 34 | 32½ | 29 | 24½ | 32 | 24 | 31¼ | 21½ | 28½ | 25½ | 21¼ | 20 | 27 g./sq. cm. |
| Standing, arm by side .. | 39½ | 35 | 35 | 25½ | 36½ | 27 | 36¼ | 26½ | 31¾ | 29½ | 20¼ | 19½ | 30 ,, |
| Standing, arm as in sling | 33½ | 28 | 28½ | 22 | 30½ | 25 | 31¼ | 23½ | 29 | 27½ | 19¼ | 19¼ | 26½ ,, |
| Arm extended, fingers apart .. .. .. | 53 | 47½ | 46 | 49½ | 57 | 49½ | 62¼ | 49¼ | 59¼ | 54¾ | 42 | 42½ | 51 ,, |

The above experiment was then repeated using a pad of absorbent cotton wool, weighing ½ ounce, beneath the bandage, and once again a series of readings was taken after allowing the dressing to settle down (Table VIII). From this it is seen that the arm was not so tightly compressed as it was when no wool was used.

## TABLE VIII

PRESSURES EXERTED ON FOREARM COVERED WITH ½ OUNCE OF COTTON WOOL, AND BANDAGED WITH A 2 INCH WHITE OPEN WOVE (FAST EDGE) BANDAGE, AFTER BEING ALLOWED TO SETTLE FOR 10 MINUTES

Bandages 1 to 6 were applied over hospital quality cotton wool, and bandages 7 to 12 over B.P.C. quality cotton wool
Each figure represents an average of 4 readings.
All readings are in cm. of water

| Number of bandage | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Seated, arm rested .. | 15¾ | 14½ | 15 | 12 | 16½ | 17 | 19¾ | 15½ | 17 | 18¼ | 10¾ | 17¼ | 15¾ g./sq. cm. |
| Standing, arm by side .. | 15½ | 16½ | 17¼ | 12¼ | 19¼ | 19 | 22½ | 17¾ | 21½ | 22½ | 17½ | 22½ | 18¾ ,, |
| Standing, arm as in sling | 16 | 13¾ | 16¼ | 11¾ | 19¾ | 17¼ | 20 | 14 | 17 | 16½ | 12 | 16 | 15¾ ,, |
| Arm extended, fingers apart .. .. | 23 | 34¼ | 27¾ | 29¾ | 27 | 39 | 42½ | 26 | 37½ | 35½ | 27 | 32 | 31¾ ,, |

A further set of experiments was then carried out using a 3-inch crêpe bandage B.P.C. to retain the wool in position, because such a dressing has been recommended to dress burns, on the grounds that the bandage will not stretch or slip (Table IX).

## TABLE IX

PRESSURES EXERTED ON FOREARM COVERED WITH ½ OUNCE OF COTTON WOOL, B.P.C. AND BANDAGED WITH A 3 INCH CRÊPE BANDAGE B.P.C. AFTER BEING ALLOWED TO SETTLE FOR 10 MINUTES

Each figure represents an average of 4 readings
All readings are in cm. of water

| Number of bandage | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Seated, arm rested .. | 19¾ | 21¼ | 20½ | 22¼ | 27½ | 26½ | 26 | 23¼ | 37¾ | 28¼ | 28¾ | 25¼ | 25½ g./sq. cm. |
| Standing, arm by side .. | 20½ | 23¾ | 22½ | 25 | 29¼ | 26½ | 30¼ | 25½ | 45 | 32½ | 33 | 31¼ | 28¾ ,, |
| Standing, arm as in sling | 19 | 21½ | 20 | 20½ | 24¼ | 22½ | 24¼ | 21¼ | 36 | 26¼ | 26½ | 24¾ | 24 ,, |
| Arm extended, fingers apart .. .. .. | 27¼ | 37½ | 29½ | 33½ | 38¼ | 34½ | 39½ | 35¾ | 53½ | 38½ | 37½ | 39 | 37 ,, |

Tables X, XI and XII show examples of the actual readings from which the figures shown in Tables VII, VIII and IX were respectively obtained. Readings could only be made to the nearest 0·5 cm. on each limb of the manometer as the colnmn of liquid never settled to complete rest.

The lowest pressure recorded on the manometer was taken as the reading for each of the first 3 positions, and the highest recorded for the fourth, as it was felt that this probably represented the maximum pressure which would be exerted beneath the bandage under normal circumstances.

Table XIII shows the fall in pressure in cm. of water from time of applying to time when "arm-resting" pressure was recorded in Tables VII, VIII and IX.

TABLE X

| Bandage number | 1 | | | | 5 | | | | 12 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arm rested .. | 34 | 34 | 34 | 33½ | 33 | 32 | 32½ | 30½ | 20½ | 20½ | 19½ | 19½ |
| Standing .. .. | 40 | 38½ | 40 | 40 | 36 | 37½ | 36½ | 36½ | 20½ | 18½ | 19½ | 19½ |
| Arm "slung" .. | 34 | 33 | 34 | 33½ | 30½ | 30½ | 30½ | 30½ | 20 | 19½ | 19½ | 18½ |
| Arm extended .. | 53½ | 53 | 53½ | 53 | 59 | 57½ | 58 | 54½ | 43 | 43½ | 43 | 41 |

TABLE XI

| Bandage number | 1 | | | | 7 | | | | 11 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arm rested .. | 16 | 16 | 15 | 16 | 19½ | 20½ | 19½ | 19½ | 12 | 10 | 11 | 10 |
| Standing .. .. | 16 | 16 | 15½ | 15 | 24½ | 22 | 22 | 21½ | 18 | 18 | 17½ | 16 |
| Arm "slung" .. | 16 | 16 | 16 | 16 | 21 | 20 | 20 | 19 | 12 | 12 | 12 | 12 |
| Arm extended .. | 23 | 23 | 23 | 23 | 42 | 44 | 43 | 41 | 27 | 27 | 27 | 27 |

TABLE XII

| Bandage number | 1 | | | | 6 | | | | 9 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arm rested .. | 20 | 20 | 20 | 19 | 27½ | 27 | 26 | 26 | 38½ | 38½ | 37 | 37 |
| Standing .. .. | 20 | 20 | 21 | 21 | 26½ | 26 | 27 | 27 | 45 | 45 | 45 | 45½ |
| Arm "slung" .. | 19½ | 19 | 19 | 19 | 23 | 22½ | 22½ | 22 | 35½ | 36 | 36½ | 36 |
| Arm extended .. | 27 | 27½ | 27½ | 27 | 34 | 34 | 34 | 36 | 54 | 54 | 53 | 53 |

TABLE XIII

Fall in pressure in cm. of water, from time of applying, to time when "arm resting" pressure was recorded in Tables VII, VIII and IX

| Bandage number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Average fall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Table VII .. .. | 5½ | 4½ | 2½ | 4 | 4 | 5½ | 3½ | 3½ | 4½ | 7 | 2½ | 2½ | 4 |
| Table VIII .. .. | 5 | 4½ | 4½ | 4 | 3½ | 3 | 3½ | 2 | 2 | 3 | 2½ | 4½ | 3½ |
| Table IX .. .. | 3 | 3 | 4½ | 3 | 7½ | 1 | 4½ | 3 | 3½ | 5½ | 5 | 2½ | 3¾ |

Additional information shown in Table XIV was obtained by once bandaging a 40-ounce bottle with a 2 inch white open wove bandage over a pad of cotton wool.

TABLE XIV

| Time in minutes from application of the bandage .. .. .. .. .. | 0 | 10 | 30 | 65 | 85 | 120 | 660 |
|---|---|---|---|---|---|---|---|
| Pressure in cm. of water .. .. .. | 66½ | 65 | 64 | 63 | 63 | 62½ | 57½ |

This gives an indication of the way in which a bandage "settles down" over a period of time, when there is no movement of muscles to assist its loosening.

Having determined the variations of pressure experienced when one individual bandaged a limb on a number of occasions, a series of volunteers then applied a similar set of bandages in order to find the range of pressures which might be met with in routine work.

The volunteers included sister tutors, trained nurses and other persons experienced in bandaging. In this series only the minimum pressure recorded as soon as the bandage was completed and when the arm was maintained in a slung position was determined (Table XV).

TABLE XV

VARIATION IN PRESSURES OF BANDAGING AS SHOWN BY DIFFERENT WORKERS. PRESSURE RECORDED AS SOON AS BANDAGE WAS APPLIED, AND TAKEN WITH THE "ARM IN A SLING" POSITION

| Worker number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| White open wove 2 inch bandage over bare forearm | 24 | 26<br>31 | 30<br>20 | 22<br>18 | 24<br>30 | 31<br>35 | 34<br>30 |
| White open wove 2 inch bandage over cotton wool | 28 | 19 | 17 | — | 23<br>20 | 19<br>21 | 20<br>24 |
| Crêpe 3 inch bandage over cotton wool .. .. | 38<br>40 | 60<br>67 | 28<br>28 | — | 35<br>29 | 31<br>36 | 44<br>35 |

## DISCUSSION

From these preliminary experiments it is seen that one worker, using a white open wove bandage over a bare arm held as if in a sling was able to produce minimum pressures falling between 19 and 33·5 g./sq.cm. after the bandage had been in place for 10 minutes. When the arm was extended with the muscles tensed the pressure beneath the bandage was approximately doubled. When a pad of cotton wool was introduced between the skin and bandage the minimum pressures ranged from 12 to 20 g./sq.cm., and again when the muscles were tensed the pressure was approximately doubled. However, when a crêpe bandage was used to retain the wool in position, the average minimum pressure reached 24 g./sq. cm. and was thus of the same order as for a white open wove bandage over the bare arm, but on exerting the muscles as on previous occasions, the maximum pressure only rose by about 50 per cent. due to the elasticity of the bandage. It appears therefore that cotton wool beneath a crêpe bandage may be subjected to a greater pressure than when beneath an open wove bandage when the arm is supported, but that the difference is much less marked when the patient uses his muscles.

When different workers applied open wove bandages, with or without cotton wool in the manner described above, it was found that the variation in pressures between one worker and another fell approximately within the range of the original experiments, but that when a crêpe bandage was used a greater variation was found. This may have been due to a certain difference of opinion between the workers as to the correct tension to use when applying this type of bandage.

It would be of interest to pursue this investigation further in order to determine the differences in pressure which result from the use of different bandaging materials, and different dressings, when used on various parts of the body. Stanton, Wilkins and their colleagues[4,5] have recently reported on the pressures required beneath elastic stockings, and suggest that when a knee-length stocking is used a pressure of from 10 to 15 mm. of mercury (i.e., about 13 to 20 cm. of water) will accelerate deep venous blood-flow in the limb and that the effect is greatest in people with dilated deep veins. Such work is not, however, comparable with this present investigation, which was undertaken with the main purpose of determining the pressure exerted by a bandage over a dressing used to absorb exudate from a burn or wound.

## SUMMARY

1. Absorbency and absorbing capacity (or water retention coefficient) are two entirely distinct properties of surgical dressings.

2. The water retention coefficient is greatly dependent on the actual working pressure on the dressing. This must be defined before any figure can be considered valid.

3. The water retention coefficient appears to vary with the degree of disorganisation of fibre arrangement in the dressing. The most regular structures, such as finely woven gauze, have the lowest water retention coefficient and the most irregular, such as cotton wool, the highest.

4. The order of efficiency of a number of dressings, when judged by the weights of liquid retained by a given weight of dressings is not necessarily the same as when the order is decided by measuring the weights of liquid absorbed by given volumes of dressings.

5. Except in the case of lint, the water retention coefficient is not apparently affected by the quality of a dressing. It is primarily a character of a particular kind of dressing.

6. The relation between working pressure and water retention coefficient is curvilinear. By taking logarithms of both variables, fair approximations to straight lines result, and the whole behaviour of a dressing in respect of water retention coefficient can be expressed by two constants.

7. The pressures under bandages have been measured, using white open wove with and without a cotton wool pad, and a crêpe bandage. It was found that a cotton wool pad reduces the pressure on the dressing, and that the pressure under a crêpe bandage falls within a smaller range of values than under a white open wove bandage when the muscles are flexed and tensed.

## REFERENCES

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2. *Extra Pharmacopœia*, 22nd Edition, Vol. 1, Pharmaceutical Press, London, 1941, p. 564.
3. Stanton, Fries and Wilkins, *J. Clin. Invest.*, 1949, **28**, 553.
4. Wilkins, Mixter, Stanton and Littler, *New England J. Med.*, 1952, **246**, 360.

## DISCUSSION

The paper was presented by DR. R. M. SAVAGE.

MR. W. R. THOMPSON (London) asked for information regarding the effects of sterilisation on the water retention coefficient.

DR. G. E. FOSTER (Dartford) asked concerning the difference in water retention coefficient of a dressing before and after compression.

DR. K. R. CAPPER (London) referred to the authors' statement that, in the case of lint, the "well raised" was an important factor in water retention, and said that "well raised" might be interpreted in various ways. It appeared that the water retention test would control the way in which the lint nap had been raised.

MR. T. D. WHITTET (London) said he was not sure how the water retention coefficient could be correlated with clinical efficiency. For example, as between rayon and cotton dressings the cotton seemed to have a better water retention coefficient, yet in quite an extensive series of tests on rayon lint the difference clinically was undetectable, and in one or two cases the rayon was considered to be preferable to cotton.

DR. K. R. CAPPER (London) said that there had been adverse comment from hospitals that rayon lint did not appear to take up exudate to the same extent as cotton.

MR. T. D. WHITTET asked Dr. Capper whether his comment referred both to glossy and matt rayon lint.

DR. K. R. CAPPER relied that he was unable to say which kind of lint was supplied to the hospitals.

MR. A. MARSH (Brighton) asked whether there was any difference between water and body fluids from the point of view of absorption.

DR. R. M. SAVAGE, in reply, said that he could give no information as to whether the water retention coefficient increased or decreased on sterilisation. A compressed cotton dressing increased in size when moistened without external pressure being applied. The important difference was that between volumetric and gravimetric water retention coefficient. For lint, the water retention coefficient did seem to provide an opportunity for giving a quantitative measure to the qualitative statement "well raised." The difference between rayon and cotton dressings was not very great. A few tests had been carried out on sulphated blood, but the field of biological fluids was so wide that it could not be incorporated in the paper.