BRITISH PHARMACEUTICAL CONFERENCE BRISTOL, 1957

SYMPOSIUM

WOUND HEALING AND DRESSINGS

By John T. Scales

Senior Lecturer, Department of Biomechanics and Surgical Materials, Institute of Orthopaedics (University of London), Stanmore, Middx., Consultant in Orthopaedic Prosthetics, Royal National Orthopaedic Hospital, London

The skin is the barrier between the outside world and the organism, it is the pliable, water vapour permeable container in which we live. Its very situation makes it the most vulnerable of all tissues to injury and infection, but in the course of evolution it has developed amazing reparative powers. In the Edwin Smith[1] Surgical Papyrus, discovered in Egypt by Smith in 1878, and believed to have been written somewhere about 1500 years B.C., there is frequent reference to materials used as wound dressings and the importance of certain aspects of treatment. Drainage of deep or contaminated wounds had been found to be essential and to keep the wound open raw fresh meat was applied for at least the first 24 hours, followed by the application of an ointment consisting of honey and ibex grease which was bound in position by bandages. The bandages which were of linen or papyrus were of the open wove type used at that time by the embalmers. There is mention of absorbent lint to remove discharge from wounds. The edges of superficial clean wounds were held together by strips of adhesive plaster which was probably made from linen bandages and glue. A similar treatment of wounds was practised by the Greek surgeons. Hippocrates describing the treatment of a head wound says: "it should not be moistened nor should it be bandaged; after cleaning the wound as soon as possible, one should dry the wound . . . for what is soonest dried up . . . thereby most readily separates from the rest of the tissue which is full of blood and life". Coming to more recent times, Joseph Lister, in a treatise "On the antiseptic principle in the practice of surgery"[2] which he read before the British Medical Association in Dublin on August 9, 1867, stated that "all the local inflammatory mischief and general febrile disturbance which follow severe injuries are due to the irritating and poisoning influence of decomposing blood or sloughs. In conducting the treatment, the first object must be the destruction of any septic germs which may have been introduced into the wound, either at the moment of the accident or during the time which has since elapsed". He achieved this by introducing phenol of full strength into all accessible recesses of the wound by means of a piece of rag held in dressing forceps and dipped into the liquid. He also applied a piece of lint dipped in phenol, overlapping the sound skin to some extent, covered with a tin cap which was daily raised in order to touch the surface of the lint with the antiseptic.

The object of the tin cap was to prevent evaporation. If it was desirable not to disturb the dressing in contact with the wound, but at the same time to keep it moist with antiseptic, a putty of common whitening (carbonate of lime) mixed with a solution of one part of carbolic acid in four parts of boiled linseed oil was applied. So long as the discharge continued, the paste was changed daily, but the lint was left in position. When the discharge ceased, the paste was discontinued, but the original lint was left adhering to the skin until scabbing was completed. He found that "if a perfectly healthy granulating sore be well washed and covered with a plate of clean metal, such as block tin (also sheet lead from tea chests was used) fitting its surface pretty accurately and overlapping the surrounding skin for an inch or so in every direction and retained in position by adhesive plaster and a bandage, it will be found, on removing it after 24 or 48 hours, that little or nothing that could be called pus is present". . . . "The clean metallic surface presenting no recesses, like those of porous lint, for the septic germs to develop in, the fluid exuding from the surface of the granulations has flowed away undecomposed, and the result is absence of suppuration". He made the point that the mere contact of a foreign body does not cause granulations to suppurate, whereas the presence of decomposing organic matter does.

Joseph Gamgee[3] on February 8, 1880, at the Queen's Hospital, Birmingham, gave a clinical lecture entitled "Absorbent and Antiseptic Surgical Dressings". He stated that "clinical experience has demonstrated the great value of absorbent materials. Discharges drain through them so rapidly that wounds are kept clean and the surrounding parts dry". He demonstrated Gamgee tissue which consists of a layer of absorbent cotton wool between two layers of absorbent gauze, combining the powers "both of compression and absorption". According to Gamgee the invention of absorbent dressings was due to Dr. Mathias, Mayor of Lausanne, but it was Gamgee's idea to combine absorbent cotton wool with the compressing gauze and it was he who first insisted that the material should be manufactured in an antiseptic manner. In his own words he states "the soothing surgical pressure is like that which you interchange with the hand of a lady, your hand adapts itself to hers and tenderly presses it wherever it can touch it, but nowhere squeezes it for fear of offending".

Paul Gerson Unna[4] was another who contributed much to the improvement of surgical dressings. In 1881, he described Unna's paste: gelatin 3 parts, zinc oxide 3 parts, glycerine 5 parts and water 9 parts. He stated that "the application was protective and soothing, excluding the air and lessening the chances of scratching and secondary infection, it provides a well-fitting covering which is easily applied and easily removed; incorporated in a bandage the paste forms an excellent support for varicose ulcers".

At the present time minor skin injuries are a major problem, both in industry and in the home. It is impossible to determine the working time lost and the inconvenience caused by puncture wounds, incisions, lacerations, and small burns. It has been estimated by Squire[5] that in this country nearly half a million skin injuries occur each day which need at

least a first aid dressing. Well over 50,000 of these injuries require attention in factory surgeries. Each year at least twenty-thousand industrial workers receive compensation for septic injuries and each worker loses on an average from two to four weeks working time.

A wound dressing is the most commonly used therapeutic agent. The variety available shows that the ideal dressing has not been produced and while it may never be possible to achieve the ideal, criteria for such a dressing can be established. These criteria are dependent on an appreciation of the anatomy and physiology of the skin, the mechanisms of tissue repair, the bacteriology of wounds and sepsis and the properties of natural and synthetic materials.

Structure of Normal Skin

Skin consists primarily of two layers (Fig. 1), the outer one being in part alive and in part dead. This outer layer or epidermis is attached to the under-lying inner layer or dermis by downward projections or rete

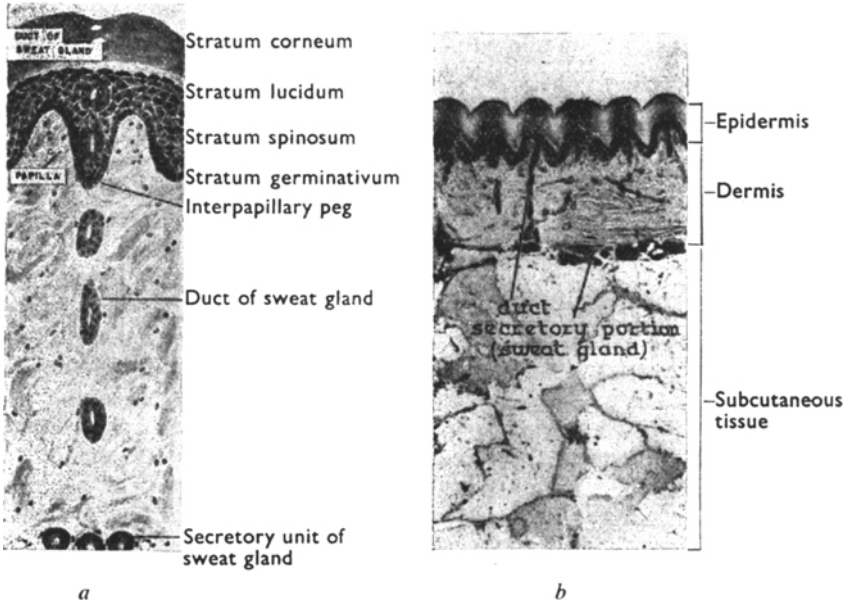

FIG. 1. *a*. Section of skin. Duct of sweat gland enters on interpapillary peg and is constituted by the cells of the different layers of epidermis through which it passes.
b. Low power photomicrograph of section of thick skin from sole of foot (from "Histology", A. W. Ham, Lippincott, London).

pegs, the upward projections of the dermis being known as the dermal papillae. This arrangement (i) allows the epithelial tissue, which consists entirely of cells, to stretch. If the reserve of cells in the rete pegs were not present, the epidermis would split, as it has little tensile strength. (ii) It allows for a reservoir of repair cells; (iii) allows an increased total contact surface between the epidermis and the dermis, and (iv) prevents

the epidermis from sliding on the dermis. The effect of the epidermis sliding on the dermis is well known to those who develop blisters after digging in the garden.

The epidermis is entirely cellular and has no blood supply or sensory endings, its metabolism being dependent on diffusion of tissue fluids from within outwards. Thus the cells nearest the source of supply of tissue fluid, that is the basal cell layer, have a satisfactory environment and are able to multiply. Above this layer the nutritional requirements of the cells cannot be met and mitotic division does not normally occur. Towards the periphery of the prickle cell layer the cells are on the verge of starvation and changes occur in their protoplasm, starting at the periphery of the cell, which result in the formation of the protein called keratin. This process is not understood but it is believed that the utilisation of glycogen is important for the proper formation of keratin. These keratin forming cells appear to have an excess of glycogen compared with other cells in the body. Finally, keratinisation is completed with death and dehydration of the cell, the keratin and cellular debris then being rubbed from the surface of the skin. Evaporation of water vapour from the skin surface, to allow full dehydration to take place, is essential. The keratin layer protects the cells beneath from bacterial infection and in its normal dehydrated state does not provide a nutrient medium for bacterial growth to occur However, being a protein it can imbibe water and swell, producing the typical macerated condition found under waterproof dressings and around soggy, wet and infected wounds. The hair follicles are in the dermis while the sweat glands extend to the subcutaneous tissue. The dermis has a rich vascular and sensory supply.

Mechanism of Wound Repair

Assume that a wound passes through the epidermis and the dermis into the subcutaneous tissue and that a small piece of the epidermis and the dermis has been lost. With penetration of the dermis there will be damage to capillary loops with bleeding which should be allowed to continue for a short time providing the bleeding is not from major vessels. The initial break in the continuity of the skin becomes plugged by a fibrin clot which is nature's first aid dressing. It prevents further loss of blood and tissue fluid, infection of the tissues and, as it dries out, contracts and pulls the skin edges together. Having plugged the hole, continuity of the skin has to be restored. This is accomplished by two distinct processes: the first, fibrous tissue repair of the dermis, and the second, migration of the epidermis. Until there is a good foundation of healthy vascular granulation tissue, free from sepsis, epithelium cannot cover the defect. If a hard thick clot plugs the wound, the contraction of the fibrous tissue in the deeper layers is retarded. Until recently it was thought that it was the basal cell layer of the epidermis which was responsible for the repair of the epidermal layer. However, it has been shown by Hartwell[6] that these cells play a secondary role in the healing process. His work has been carried out on pigs and man, the pig being used because its skin and subcutaneous tissue are similar to that of man.

While the two processes of wound healing are distinct they are intimately related and proceed simultaneously. At the edge of the wound the epithelial cells in the middle layer of the prickle cell layer migrate towards the defect: they become amoeboid. As the cells at the edge of the wound move, so the cells adjacent to them change their shape and move in the same direction. This process continues for some distance away from the wound. Hartwell[6] has shown that these mobile cells have entirely different staining and morphological characteristics to the stationary cells. Gradually, as this moving membrane of epidermal cells extends, the basal cells supply an increasing number of cells to the prickle cell layer. Any islets of epidermis which may have been left behind, such as a hair follicle or sweat duct, proliferate. Providing the repair of the dermis is continuing to keep step with the epidermis all is well. The lower cells of the migrating membrane form the new basal cell layer and these cells in turn divide and produce more cells to thicken up the epidermis (Fig. 2). If, however, the wound is infected with pathogenic organisms and there is a mass of stagnant and necrotic debris, the process is impeded. Should the granulation tissue formation be too rapid, migration of the epidermal membrane cannot take place. These granulations have then to be "burnt down" with, for example, silver nitrate. This overgrowth of granulation tissue occurs if the area of epithelial loss has been too great, when there is continual trauma of the epidermal layer, or infection. One important cause of delayed healing is the dressing. If this covers a mobile part, such as a finger, then, every time movement occurs, there will be abrasion of the delicate film of epidermal tissue. Even more important is the adhesion of the dressing to the wound. The upper layer in the migrating sheet must lose water if proper keratinisation is to occur. This is also essential for the control of bacterial growth. However, if the dressing pad dries out completely and adheres to the surface of the wound, or is of a fibrous nature so that the fibres become incorporated in the tissues, then each time the dressing is changed damage will result. A continual battle is therefore waged between those who dress the wound and the reparative powers of the

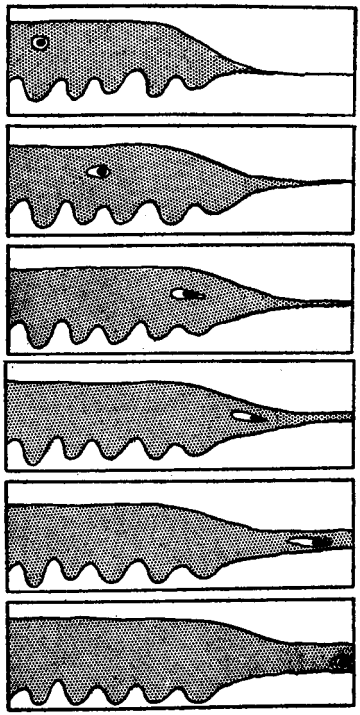

FIG. 2. Diagrams to show how a "prickle cell" in the epithelium bordering a wound can become a "basal cell" in the healing extension membrane of epithelial cells. (From "Mechanism of Healing in Human Wounds", S. W. Hartwell, Thomas, Illinois, U.S.A.)

patient. A dressing must be such that it will absorb by capillarity excess secretions and allow the evaporation of water vapour, but will not adhere to the wound or exudate. It is essential that all dressings which are stuck to wounds be moistened with saline. To protect the healing wound, particularly in exposed areas, such as the hand or foot, a certain minimum thickness is required. There must be a compromise, therefore, between what is required for protection and absorption, and what can be tolerated by the patient if he is to continue his occupation. Again, immobility of a wound is desirable, but this is rarely possible particularly in minor injuries of the hand. The pressure exerted on a wound by the dressing pad is important provided that the surface in contact is of a smooth nature. Cells are able to migrate more readily if they are able to move between two planes, rather than on one. Ideally the pad should not be of a fibrous construction, but be a continuous film. Thus the primary functions of a dressing emerge. They are, to absorb tissue fluid, tissue breakdown products, and blood, to protect the wound from injury during healing, to prevent infection, and to allow the evaporation of water vapour from beneath the dressing.

Wound Infection

We come now to the exceedingly complex problem of wound infection, the only full and exhaustive study of which being probably that of Williams and Miles[7]. They found that 20 per cent of wounds, swabbed within six hours of injury, were infected with *Staphylococcus aureus*. Contamination was commoner in those patients who normally carry the *Staph. aureus* on the skin—60 per cent of those with staphylococcal infection were the result of contamination from the patient's own skin. They investigated the bacterial flora of 487 septic wounds and other septic lesions that required operative treatment and found that *Staph. aureus* and *Streptococcus pyogenes* were the chief organisms causing infection. 86 per cent of these septic wounds yielded *Staph. aureus* and 22 per cent *Str. pyogenes*. While the staphylococcus appeared early in the wound, the streptococcus was a late infector and was usually the result of cross infection at some stage during treatment. More than 35 per cent of clinically healthy wounds yielded *Staph. aureus* on culture.

Wound Cleansing Agents and Medicaments

A great deal has been written and much publicity is still given to various agents which are said to kill organisms in a wound. While tests *in vitro* may show bacteriostatic or bactericidal properties, their effects on the tissues may limit their use *in vivo*. In 1942, Barnes[8] described the antiseptic properties of cetrimide. Williams and others[9] found that it was bactericidal to Gram-positive cocci, for example, the staphylococcus, *in vitro*, although Baker, Harrison and Miller[10] had stated that this activity was impaired in the presence of proteins and certain fats. Swabs taken from normal skin treated with cetrimide are found to be sterile; in addition it is a good detergent removing dirt and oil very effectively without causing the patient pain. Jacoby[11] showed that the surface layer of cells

treated with cetrimide is destroyed. Thus, in healing wounds, the delicate layer of migrating epithelial cells, which is endeavouring to cover the granulating surface, may be damaged. Squire[12] and others have observed dermatitis after its continual use, and it is, therefore, better to restrict it to the initial cleaning of a wound. At subsequent treatments either a dry swab, or one moistened, but not dripping, with saline should be used. While the local application of these agents may reduce the bacterial flora, the damage which they do to the tissues, either in causing its immediate death or inducing a hypersensitivity or allergy, may be of greater significance. Sensitisation after the use of sulphonamides and penicillin have been seen frequently. Williams and Miles[7] have stated that "drug treated wounds appear to heal slowly and in two small burns repeated drug treatment was associated with considerable sloughing of granulations in the absence of any demonstrable infection. Repeated applications of powders often lead to hard caking in the wound, but this could be avoided by the use of impregnated lint dressings". By repeated small doses, the drug resistant organisms may dominate the picture. It is important to remove necrotic material and debris from wounds at an early stage and allow free drainage. Whether bactericidal agents carried by the dressing are of use is doubtful, other than for the sterilisation of the dressing itself.

Importance of Porosity of Dressing

Wound dressings should allow the evaporation of water vapour from the wound area. Beneath a dressing a considerable quantity of water may accumulate. This arises from the sweat glands of the skin surrounding the wound; from normal insensible water vapour loss through the epidermis and from the dehydration of epidermal cells; and from tissue fluid lost from the wound itself.

Burch and Winsor[13] showed that approximately 1·63 g. of water are lost per sq. metre of the body surface every ten minutes, the relative humidity of the surrounding atmosphere being 50 per cent and at an ambient temperature of 75° F. This represents 235 g./sq. metre of body surface per 24 hours, or assuming the average adult body to have a surface area of 1·8 sq. metres, 423 g./24 hours. They also found that the loss of tissue fluid from the floor of a blister raised by cantharides was nearly ten times as great. Thus from their figures, a dressing would need to have a porosity of approximately 2340 g./sq. metre/24 hours. This high porosity is, of course, only necessary for that area of the dressing which corresponds to the area of the wound and for the period when the wound is actively losing tissue fluid. Bull, Squire and Topley[14] reported on experiments with a plastic film dressing—Nylon, I.C.I. type 8—which had a porosity of 600 g. of water vapour per sq. metre per 24 hours, at 100° F. with a differential water vapour pressure of 55 mm. of mercury across the film. In preliminary experiments on normal skin it was found that, if a Nylon dressing was left *in situ* for three days or more, *Staph. aureus* could not be recovered from beneath the window of the uncoated area of the dressing. The only organisms that could be cultured from the covered area were of the *Staph. albus* group. This reduction of bacterial flora and

the absence of *Staph. aureus* was not due to any chemical effect of the Nylon film. Their work demonstrated that the skin, if it were not continually reinfected, would, in fact, be free of pathogens. If a non-porous waterproof dressing covers the skin, there is a quantitative increase in the staphylococcal flora. Why there should be a difference under porous and non-porous cover is not clear. Both types of dressings prevent contamination of the skin by micro-organisms under normal conditions. Brann[15] found that human hair rarely carries pathogenic organisms. He suggested that the fatty acids of the scalp might be bactericidal. Marchionini and others[16,17] demonstrated the importance of the "acid mantle" for skin protection from bacterial invasion. Burtenshaw[18] showed that the sterilising effects of the skin depended mainly on the unsaturated fatty acids in the sweat and sebum. Ricketts, Squire and Topley[19] found that it was the long chain fatty acids, particularly oleic acid, which were responsible. Under both the micro-porous and occlusive dressings the fatty acids are retained. Incomplete dehydration of the keratin coupled with a change in the gaseous environment under a non-porous dressing may be responsible for the difference in bacterial flora.

Experimental Work on Wound Healing

Some interesting work on the comparison of wound healing with and without dressings was carried out by Heifetz, Lawrence and Richards[20] on clean surgical wounds of the anterior abdominal wall of rabbits. They found that well coapted wounds heal equally well whether they are covered by cotton gauze dressings or not. They thought that the absence of a dressing allows quick drying of the surface coagulum and this gives an early protection to the wound. When they repeated their work with the surgical wounds in human subjects, they found the following requirements had to be fulfilled if a dressing was not applied. There must be no local anaesthesia of the wound, sharp dissection and minimal undermining of the tissue planes, gentle handling of the tissues at operation, almost complete haemostasis with no dead space, insertion of non-absorbable sutures, absence of contamination and debris in the wound, accurate coaptation without strangulation of tissues, no drains, and absence of interference with the wound by the patient.

Bacterial counts taken from clinically aseptic wounds showed statistically no significant differences whether or not the wound was dressed, although the data suggested that the bacterial counts were, in fact, lower in those wounds where gauze dressings had not been applied. Körlof[21] investigated different methods of treating pyocyaneus infected burns of guinea pigs. He used polymyxin B, an antibiotic produced by a strain of *Bacillus polymyxa* and effective against pyocyaneus *in vitro*, phenoxetol, also effective in dilution 1 in 500 in broth, and chlorophyll. He found that the mortality of the animals was considerably lower if no dressing or a porous dressing was used, than in those cases in which a thick occlusive dressing had been applied; there was also a diminution of the bacterial growth in those wounds exposed to the air. The therapeutic agents employed had no effect on the pyocyaneus infection or on the rate

of healing of these experimental wounds. Baron[22–25] in a series of papers from 1951 to 1955, has studied the effects of textiles on standard wounds in guinea pigs. He believes that the open air treatment of wounds should be used only for wounds of a superficial nature, that compression by a plate of Cellophane prevents loss of tissue fluid and congestion of the surrounding tissues, and that textile drainage allows the removal of wound secretion with a reduction of infection of wounds. His experiments show that the indiscriminate use of wound textiles, without regard to the number of layers used or character of the fabric, increases the mortality rate of experimental animals. The finishing processes applied to wound textiles have an undesirable effect on wounds[26], the use of titanium dioxide and optical whiteners being frequently the cause of delayed healing. Non-delustered viscose rayon wool which has a yellowish tinge and is glossy has a favourable influence on wound healing when compared with the delustered white viscose rayon wool. All agents which are added to give a pleasing appearance to the material and which serve no useful purpose should be avoided.

Criteria of an Ideal Dressing

Although the type and severity of wounds vary widely and the dressing may be required for a variety of purposes and may be a composite structure, it should possess the following properties (Scales[27]). It should:

(1) have a porosity to water vapour of at least 1400 g./sq. metre/24 hours, measured at 37° with a relative humidity of 75 per cent (Patra Tentative Standard Method[28]);

(2) absorb wound exudate but not adhere to a granulating surface or allow the penetration of capillary loops;

(3) not produce a tissue reaction when applied to normal skin or granulating surfaces, nor induce a state of allergy or hypersensitivity;

(4) not allow the passage of micro-organisms;

(5) not allow penetration of fluid from outside;

(6) be capable of following the contours around a joint during movement, e.g., flexing of a finger;

(7) not be affected by domestic or industrial fluids, e.g., detergents and oils;

(8) be smooth on both surfaces;

(9) have adequate tensile strength;

(10) have constant physical properties between 0° and 40°;

(11) be non-inflammable;

(12) be capable of being sterilised;

(13) prevent excessive movement of the wound;

(14) not become readily soiled;

(15) be available at low cost; and

(16) be capable of being sealed to the skin by an agent which is both unaffected by all solvents used in industry and at the same time easily removable.

So far these criteria have not been satisfied in any one dressing.

The most commonly used dressing, the sterile gauze pad covered with cotton wool and a bandage, will allow the evaporation of water vapour and will absorb exudate. However, it adheres to wounds and, if it becomes damp, allows the passage of micro-organisms. Various fats and oils, e.g., tullegras, can be used to prevent adhesion between the wound and the dressing, although these often appear to delay healing. The passage of organisms through a dressing has been demonstrated by Colebrook and Hood[29] using a "mock limb" which consisted of a metal tube, perforated at one place to represent a wound. The perforations were covered by a pad which could be soaked in sterile broth. The "wound" was dressed in the traditional manner with gauze, cotton wool and bandage and the whole sterilised. The wound would remain sterile provided the dressing was not dampened with serum containing organisms. In a very short time after such treatment the "wound" became infected.

This type of dressing is often difficult to apply and is completely unsuitable for domestic and industrial injuries, both because of its bulk and the impossibility of its remaining dry and, in industry the risk of a loose bandage catching in machines. The development of the fabric elastic adhesive dressing was an endeavour to provide a covering which would be easier to apply coupled with a degree of compression, depending on the method of application, and at the same time, because of its continuous film of rubber adhesive, would prevent the passage of organisms across the dressing. The form of the weave gave elasticity to the dressing, with consequent increase of freedom of movement of the part. It has proved only partially successful. The adhesive hinders the evaporation of water vapour and the subsequent drying of the wound, especially in those areas where marked sweating occurs.

Owens[30] showed that when a rayon fabric dressing with a fibre of 30 denier and a warp and weft of 114 $\times$ 114 is applied to a burn, there is little disturbance of the underlying granulation tissue and pain and bleeding are diminished and infection reduced. The dressing had a high porosity and a pore size of less than 8 μ. The size of capillary buds is approximately 8 μ. Although granulation tissue did not penetrate the fabric, adhesion to the wound occurred and it was necessary to moisten the dressing with saline to prevent reopening of the wound.

With the development of synthetic materials during the war, plastic films became available which appeared to have many desirable properties, although for all practical purposes they had no water vapour permeability. These early materials were types of plasticised polyvinyl chloride. It was thought by some workers that a waterproof dressing provided with an absorbent pad would be satisfactory, as the initial high loss would be absorbed by the pad. In the chemical industry and under the Chromium Plating Regulations the provision of a waterproof dressing has become compulsory. It was soon found, however, that these dressings had disadvantages; the skin became macerated, the edges of the wound gaped, with subsequent delay of healing, and the plasticiser was migratory and was removed from the film by various organic solvents.

Bloom[31] reported the use of water wettable Cellophane in the treatment of burns in the Army. The material was the wrapping from blood transfusion sets and was sterilised by autoclaving. The Cellophane formed a semipermeable covering—not an occlusive dressing. The Cellophane was porous, yet prevented secondary infection; it was smooth and partially flexible and allowed the wound to be seen. When dry, however, Cellophane is brittle and relatively inelastic and after a few days it cracks at flexures. It is easily torn, and a sheet $1\frac{1}{2}$ thou. in. in thickness, gives little protection to the wound. Another film material, polyvinyl alcohol, was investigated, but had no advantages over Cellophane. Once a film of serum forms over the surface of these materials, the permeability is markedly reduced.

Bull, Squire and Topley[14] reported experiments with another plastic film—Nylon I.C.I. type 8, 3 thou. in. thick. The use of this film as an industrial wound dressing was investigated by Schilling and others[32] and Engel[33]. In the clinical trial, Schilling used a standard waterproof dressing as a control. Healing times were:—

Nylon type 8 dressings	6·04 days.
Waterproof dressings	8·39 days.

It seemed that this film would be useful in the control of secondary infection of bedsores and tuberculous sinuses and it was for this reason that its use was investigated by the Institute of Orthopaedics. It was found that the porosity of the samples of film obtained from the manufacturers was about 200 g. of water vapour/sq. metre/24 hours at 37°, relative humidity 75 per cent (using the Patra[28] technique), that adhesive was difficult to apply and that the seal was even more difficult to maintain, due to the lack of elasticity of the film. Further, maceration of the skin occurred around sinuses and bedsores due to the accumulation of exudate which was retained beneath the film in contact with the tissues. Whilst there was evaporation of water vapour, the osmotic pressure of the discharge increased and this resulted in a subsequent increase of exudate. When removing the backing from a Nylon adhesive dressing it was difficult to prevent the film from curling. The work of Bull, Squires and Schilling, however, once more demonstrated the advantages of porous materials. The Nylon film dressing used by Schilling did not have a pad, but this is necessary to protect the wound from injury and to absorb blood and exudate particularly if the dressing is of the first aid type.

One of the functions of a dressing is to absorb secretions. It must be able to absorb fluid rapidly and the approximate value of this property can be obtained from the sinking test which is described in the British Pharmaceutical Codex. It is dependent on the physical properties of the surface of fibres and on the construction of the yarn if the fabric be knitted or woven. The rate of absorption is not, however, necessarily related to the quantity of fluid which the dressing is capable of absorbing. Work has been done on this problem by Savage, Bryce and Elliott[34]. They thought it better to replace the term "absorbing capacity" of a

dressing by the term "water retention coefficient" in order to avoid confusion with absorbency or rate of absorption of fluids into a dressing. They have defined the water retention coefficient as the number of grams of water absorbed per gram of dressing. Equal weights of cotton and rayon wool dressings were able to retain a greater weight of water than woven forms of surgical dressings. These were followed by paper pulp, cellulose wadding, lint, open gauzes, B.P.C. and hospital qualities, and the finer gauzes used in other countries, in decreasing order of efficiency. As was to be expected, it was found that all these materials absorbed less as they were compressed under increasing loads. It is important to remember this point, since the amount of fluid which a dressing is capable of absorbing will depend on how the dressing has been treated before it is used, i.e., during storage and sterilisation, and under what tension or compression it is applied to the wound. While the rate and the volume of fluid absorbed by the dressing is important, it is equally necessary that the dressing does not remain saturated and that it loses water vapour in the shortest possible time and allows a coagulum to form to which it does not adhere.

Spray-on Dressings

Wallgren[35] investigated the flora under five spray-on plastic film dressings. The following were used:—

1. Aeroplast, which is an ethyl acetate solution of co-polymers of hydroxyvinyl chloride-acetate and sebacid acid 9·3 per cent by weight, and modified maleic resin ester 3·1 per cent by weight with fluorochlorohydrocarbon gas as a propellant.
2. Bonoplast, which consists of an acrylic resin dissolved in ethyl acetate, a plasticiser being added.
3. An improved form of this material is now being manufactured by the same company under the trade name of Nobecutan. This dressing consists of a 4 per cent solution of polymethacrylic acid ester with an ether bridge in the alcohol component. The solvent is ethyl acetate. A fluorohydrocarbon is used as a propellant. The solution used abroad contains 0·5 per cent by dry weight of tetramethyl thiuramide disulfide. (The preparation available in Great Britain is a sterile solution containing no added bacteriostat or bactericide.)
4. Newskin, which consists of pyroxylin 6·9, camphor 0·6, castor oil 3·0, butyl alcohol 5·0, ethyl acetate 57·3 and ethyl alcohol 25·0 per cent, is supplied in tubes, not as an aerosol.
5. Portex plastic skin consists of phenyl salicylate 10, resorcinol 5 and eugenol 25 per cent, and a methyl ester of an acrylic resin.

The experiments were conducted mainly on blood agar plates and on intact human skin. All the products listed were found to be sterile. One loopful of bacteria, approximately 6×10^8 ml., was mixed with 1 ml. of the plastic solution and samples were taken at fixed intervals. Table I indicates the maximum intervals after which bacterial growth could no longer be obtained. It was found that only Nobecutan gave a zone of inhibition when a test culture on a blood agar plate was half covered by a

plastic film. The bacteriostatic agent was tetramethyl thiuramide disulfide. They found, however, that *Staph. pyogenes* could sometimes be grown when swabs were taken from underneath the Nobecutan film. The authors believed that the bacteriostat was in some way inhibited by the constituents of the plastic film. They found that if a film was sprayed on to a culture plate, both proteus and coli organisms could be recovered from beneath the film when the exposed surface of the film was inoculated.

TABLE I

BACTERICIDAL ACTIVITY OF SPRAY-ON DRESSINGS[35]

	Staph. aureus	*Proteus vulgaris*	*Pseudomonas aeruginosa*	*Escherichia coli*
Aeroplast	5 min.*	1 min.		1 min.
Bonoplast (smear) ..	17 days	1 min.	1 hour	1 min.
Bonoplast (spray) ..	17 days	1 min.	1 hour	1 min.
Newskin	2 min.	1 min.	1 min.	1 min.
Nobecutan (spray) ..	15 min.	1 min.	1 min.	2 min.
Portex	1 min.	1 min.	1 min.	2 min.

* The times indicate the maximum intervals after which bacterial growth could no longer be shown after the addition of approximately 6×10^8 organisms per ml. to the plastic solution.

Therefore, there must have been holes in the film produced during spraying of 0·8 μ–1·0 μ in size. A film thickness of 60 μ to 90 μ which required four to five coatings by spraying, would prevent through-growth. They found that when cultures were taken underneath films applied to normal skin 24 hours previously, the number of colonies recovered decreased by 50 to 100 per cent, compared with normal skin. Portex plastic skin was not suitable as the film would not remain whole and was difficult to remove. When the thickness of the plastic film was increased, the bacterial flora increased. Wallgren[35] has now treated over 4500 patients with "spray-on" dressings and although infections have occurred, the incidence has been below the three to five per cent, reported by Beekman and Sullivan[36] and Hirschfeld[37] to be the normal incidence of wound infection in sterile surgery. He thinks that Nobecutan and Aeroplast are superior to other film type dressings which he has tested. These films, however, cannot be used in the treatment of a wound which is bleeding or infected, nor are they suitable for wounds such as those on the hand, which are subject to continuous flexion and trauma. For first aid purposes the adhesive dressing is certainly more convenient.

Microporous Polyvinyl Chloride Film

With the difficulties experienced with a variety of dressings and the properties of an ideal dressing in mind, it was decided to investigate a physically porous membrane—Porvic which is used for battery separator plates. It allowed the passage of electrolytes and had the advantage that the base material was one of the cheapest plastics, this being a major consideration in an investigation of this type. No matter how advantageous

a material may be for a dressing, if the cost is three or four times above the cost of existing dressing materials, then it is doubtful if any manufacturer would be willing to carry out the necessary experimental work which is required in this field.

Our initial experiments were carried out with plasticised battery separator plates having a porosity of about 4000–5000 g. of water vapour/sq. metre/24 hours at 37°, relative humidity 75 per cent (Patra tentative standard method[28]). This material was not a bacterial filter or barrier. It had, however, the elasticity and plasticity required. Ulcers and wounds which had been slow to heal improved or healed in a short space of time when these dressings were used. It was soon found that a non-migratory plasticiser was needed, as the physical properties of the film altered during storage and the plasticiser migrated into the adhesive with a change in its characteristics. Migratory plasticisers are quickly removed by certain industrial solvents with a resulting change in the physical properties of the film.

The manufacture of a physically porous material which is required to act as a bacterial filter presents many technical problems. The staphylococcus has a minimum measurement of approximately 0·7 μ. Whether the filter must thus have a pore size of less than 0·7 μ still remains to be determined. It is known that organisms and membranes carry electrostatic charges. The part these play, especially in the presence of detergents or serum which reduce surface tension is not known.

Over 350 batches of film material have been produced and examined as well as many formulations of adhesive spread tested.

As a result of a number of clinical trials, a microporous dressing (M.P.F.) is now available[38], which allows the passage of 1400 to 1800 g. of water vapour per sq. metre/24 hours at 37° with a relative humidity of 75 per cent or a water vapour pressure gradient across the film of 46·6 millibars. The film carries an adhesive, spread in a diamond pattern. The pad, which is of cotton stockinet, is impregnated with 0·1 per cent domiphen bromide B.P.C. Although a cotton pad has been used, a continuous filament viscose rayon pad would be more suitable, since the risk of leaving fibres in the wound would be reduced. Clinical trials using a standard waterproof (O.F.) dressing as a control which also carried a cotton stockinet pad impregnated with 0·1 per cent domiphen bromide, were made on the normal skin of patients in hospital and on patients who attended a surgery of the London Transport Executive for first aid treatment of minor injuries.

Normal Skin—Bacteriological Studies

The normal skin flora of both forearms of 39 male and female hospital patients was determined by daily swabbing for four or five consecutive days. Three dressings of each type were then placed on the forearm of these patients. One of each kind was removed at 24 hour intervals, the skin beneath the pad being swabbed. The results are shown in Tables II and III, and Figure 3.

Minor Injuries—Bacteriological Studies

Complete studies were possible only in 60 cases. The results are given in Table IV.

It can be seen from Tables III and IV and Figure 3 that, when normal skin and wounds are covered with a microporous film carrying a pad impregnated with 0·1 per cent domiphen bromide, the no-growth recovery rate is increased. The healing time for finger wounds was reduced under microporous dressings compared with occlusive dressings.

TABLE II

BACTERIOLOGICAL STUDIES OF NORMAL UNCOVERED SKIN

No. of patients swabbed	Total No. of swabs examined	No growth	Scanty	Heavy
39	346	25 (7·2 per cent)	220 (63·6 per cent)	101 (29·2 per cent)

TABLE III

NO GROWTH RECOVERY RATE EXPRESSED AS A PERCENTAGE

	24 hours	48 hours	72 hours
Normal skin	7·2	—	—
Porous dressing ..	59	82	74
Non-porous dressing ..	15·3	2·55	10·2

TABLE IV

BACTERIOLOGICAL STUDY OF MINOR INJURIES

Type of dressing	Initial swab		24-hour swab		48-hour swab	
	Growth	No growth	Growth	No growth	Growth	No growth
M.P.F., 29 cases ..	18	11 (37·5 per cent)	20	9 (30 per cent)	16	13 (44 per cent)
O.F., 31 cases ..	14	17 (55 per cent)	26	5 (16 per cent)	27	4 (13 per cent)

Pads in Contact with the Wound

The replacement of the traditional cotton pad is being investigated. The use of a cotton pad may, in fact, be a bad procedure. Once the cotton has become wet it retains water, resulting in sogginess and maceration of the skin. No dressing film, no matter how porous, will allow drying out of a cotton pad within a reasonable time. The cotton fibre is of short length, irregular in cross section and it has a rough crystalline surface. Artificial fibres are available as continuous filaments of regular cross section and having a smooth surface. They can be obtained free of contaminants. Preliminary experiments using a standard adhesion technique with serum have shown that the following factors have to be considered in choosing a fabric which is to come into contact with a wound.

The composition of the fibre, its surface and any residual agent left in the fibre. The size of the fibre. The construction of the yarn, and the construction of the fabric.

With rayon, which is a regenerated cellulose fibre, a continuous filament of regular cross section and having a smooth surface can be obtained. Experiments which we have carried out at Stanmore suggest that continuous filament rayon fabrics adhere less to wounds than cotton fabrics.

Fixation of Dressing to Skin by Adhesives

Even if the dressing has all the desirable properties, the maintenance of the seal between dressing and skin is all important.

Fixation of a dressing is best achieved by pressure-sensitive rubber-based adhesives. As porosity is a feature of the resultant dressing, the application of an adhesive should impair this property to a minimal degree. With a window dressing, with a non-porous adhesive spread, an appreciable area is rendered non-porous and the bacterial flora beneath the adhesive increases; the conventional pad is difficult to fix, and production is cumbersome and costly. The ideal dressing will need to carry a porous adhesive spread. Immediate "tack" and strong adhesive are two distinct properties which must be combined in a pressure sensitive adhesive. Moreover, the adhesive must remain integral with the dressing film so that the film does not slide on the adhesive. Careful application of the dressing to the patient is vital. If there are creases or unstuck areas where fluid can penetrate, or if the seal is not maintained, then the main object of the dressing, i.e., prevention of infection coupled with porosity to water vapour will be defeated.

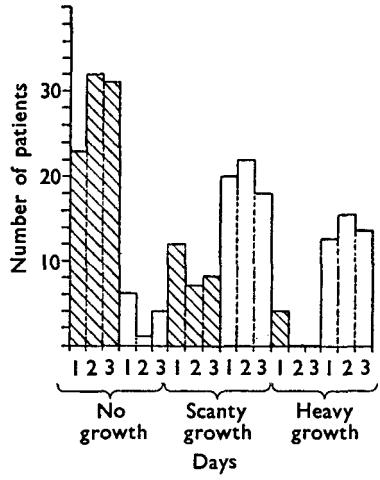

FIG. 3. Results of bacterial studies on normal skin.

Shaded area, porous dressing, M.P.F.
Non-shaded area, non-porous dressing, O.F.

Preparation of the Skin

To maintain an adhesive dressing *in situ*, the skin must be dry. Many worker's hands become covered with water and oils during the course of a shift. It has been found that when dressings are applied towards the end of a shift it is almost impossible to maintain a seal unless the area to which the dressing is to be applied has been adequately cleaned and dried with methylated ether. Fingertip injuries present a particularly difficult problem as the cleft between the nail and the skin invariably allows leakage of fluids to occur. A fingerstall type of dressing requires to be devised but this presents many difficulties.

Have wound dressings been improved in the last 3500 years? I think the answer is yes, but many of the problems have yet to be solved. At

the present time the best dressing is but a compromise and is a poor substitute for an intact healthy skin.

I would like to thank the Medical Research Council, who are assisting with a grant, work on certain aspects of wound dressings.

REFERENCES

1. Breasted, *Edwin Smith Surgical Papyrus*, Chicago University Press, 1930.
2. Lister, *Lancet*, 1867, **2**, 353.
3. Bailey and Bishop, *Notable Names in Medicine and Surgery*, H. K. Lewis & Co. Ltd., 1946, p. 93.
4. Bailey and Bishop, *ibid.*, p. 133.
5. Squire, *Plastics Progress*, p. 267, Papers and Discussions at the British Plastics Convention 1951, Iliffe and Sons Ltd., 1951.
6. Hartwell, *The Mechanisms of Healing in Human Wounds*, Charles C. Thomas, Springfield, Illinois, 1955.
7. Williams and Miles, *Medical Research Council Report*, 1949, No. 266.
8. Barnes, *Lancet*, 1942, **1**, 531.
9. Williams, Clayton-Cooper, Duncan and Miles, *ibid.*, 1943, **1**, 522.
10. Baker, Harrison and Miller, *J. exp. Med.*, 1941, **74**, 621.
11. Jacoby, *J. Physiol.*, 1943, **102**, 4P.
12. Squire, see *Medical Research Council Report*, 1949, No. 266, p. 63.
13. Burch and Winsor, *Arch. intern. Med.*, 1944, **74**, 428.
14. Bull, Squire and Topley, *Lancet*, 1948, **2**, 213.
15. Brann, *Klin. Wschr.*, 1928, **7**, 2059.
16. Marchionini and Hausknecht, *ibid.*, 1938, **17**, 663.
17. Schade and Marchionini, *ibid.*, 1928, **7**, 12.
18. Burtenshaw, *J. Hyg.*, 1942, **42**, 184.
19. Ricketts, Squire and Topley, *Clin. Sci.*, 1951, **10**, 89.
20. Heifetz, Lawrence and Richards, *Arch. Surg.*, 1952, **65**, 746.
21. Korlof, *Acta chir. scand.*, 1954, **107**, 244.
22. Baron, *Berichte, Erkentnisse, Anregungen* (1851–1951), Lohmann K.G., Fahr/Rhein.
23. Baron, *Langenbecks Arch. Dtsch. Z. Chir.*, 1953, **274**, 510.
24. Baron, *Arzneimitt.-Forsch.*, 1955, **5**, 78, 127.
25. Baron, *ibid.*, 1955, **5**, 237.
26. Baron, *Nature, Lond.*, 1955, **175**, 760.
27. Scales, *Trans. Ass. industr. med. Offs.*, 1954, **4**, 69.
28. Ginsborg and Poulter, PATRA 1948, Packaging Research Report No. 2.
29. Colebrook and Hood, *Lancet*, 1948, **2**, 628.
30. Owens, *Surgery (St. Louis)*, 1946, **19**, 482.
31. Bloom, *Lancet*, 1945, **2**, 559.
32. Schilling, Roberts and Goodman, *ibid.*, 1950, **1**, 293.
33. Engel, *J. Industrial Nurses*, 1953, **5**, 505.
34. Savage, Bryce and Elliott, *J. Pharm. Pharmacol.*, 1952, **4**, 944.
35. Wallgren, *Acta chir. scand.*, 1957, **112**, 161.
36. Beekman and Sullivan, *Surg. Gynaec. Obstet.*, 1939, **68**, 1059.
37. Hirschfeld, *ibid.*, 1941, **73**, 72.
38. Scales, Towers and Goodman, *Brit. med. J.*, 1956, **2**, 962.