Brit. J. industr. Med., 1963, **20**, 82.

WOUND HEALING AND THE DRESSING*

BY

JOHN T. SCALES

From the Department of Biomechanics and Surgical Materials, Institute of Orthopaedics, University of London

(RECEIVED FOR PUBLICATION ON SEPTEMBER 18, 1962)

The evolution of surgical dressings is traced from 1600 B.C. to A.D. 1944.

The availability of an increasing variety of man-made fibres and films from 1944 onwards has stimulated work on wound dressings, and some of the more important contributions, both clinical and experimental, are discussed. The functions of a wound dressing and the properties which the ideal wound dressing should possess are given. The necessity for both histological and clinical evaluation of wound dressings in animals and in man is stressed.

Wound dressings are the most commonly used therapeutic agents, but there is no means whereby their performance can be assessed. An attempt should be made either nationally or internationally to establish a standard method of assessing the performance of wound dressings. For this it is necessary to have an internationally agreed standard dressing which could be used as a reference or control dressing in all animal and human work. The only animal with skin morphologically similar to that of man is the domestic pig. Three types of wounds could be used: (1) partial-thickness wounds; (2) full-thickness excisions; and (3) third-degree burns.

The development of standard techniques for the assessment of the efficiency of wound dressings would be of considerable benefit to the research worker, the medical profession, the patient, and the surgical dressings industry.

It could be supposed that by now the medical profession should be able to define the properties required of various dressings; but this is not so. Wound healing is a complex process which is not yet fully understood. It is influenced by many factors, not the least important being the local environmental factors which can be harmful or beneficial depending on the properties of the dressing.

It is necessary to examine the history of dressings in order to appreciate how clinical trial rather than systematic experiment has until very recently been the usual way in which dressings have been investigated. The products of the polymer chemist have stimulated research along new lines, and I believe that the synthetic fibre industry must increasingly interest itself in wound healing, even though the immediate reward in terms of weight of fibre and film consumed may seem small. Likewise, the medical profession must co-operate more with the industry if improvements in treatment are to be made.

*Paper presented at the Second World Congress of Man-made Fibres in London, May 1962, and reproduced by permission of the Comité International de la Rayonne et des Fibres Synthétiques.

Evolution of Dressings 1600 B.C. to A.D. 1944

Blakiston's Illustrated Pocket Medical Dictionary (1952) states that the chief functions of a bandage are "to hold dressings in place, to apply pressure, to immobilize a part, to support a dependent or injured part, to obliterate tissue cavities and to check haemorrhage". A dressing is described as "material applied to protect a wound and favour its healing". The two terms have been and are used indiscriminately.

A wound dressing is still the most commonly used therapeutic agent, and it is probably true to say that the foundations of the art and science of medicine were laid when early man first treated wounds. Here we are concerned principally with natural and synthetic dressing materials, *i.e.* those materials which come into contact with the wound or have an effect on the wound environment.

In the Edwin Smith and Ebers Papyri, which were probably written between 1600 and 1500 B.C., there are frequent references to fabrics used for bandages and dressings and the importance of certain aspects

of treatment, for example, the drainage of deep or contaminated wounds. All manner of medicaments were applied to the wound, from dung to honey. Hippocrates (400 B.C.), 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." This sound advice was not always practised by Hippocrates, who also used many noxious agents to stimulate pus, which was thought to be a precursor to wound healing. Celsus and Galen (25 B.C. to A.D. 200) believed in the closed treatment of wounds with the use of a bewildering assortment of medicaments to promote pus and wound exudate. The dogma of "laudable pus" persisted into the thirteenth century, when a revolt against this teaching was started by Theodoric de Lucca, a member of the Dominican order in Bologna. He wrote, "It is not necessary, as Roger has written, as his disciples declare and as all modern surgeons teach, that pus should be generated in a wound; no error can be greater than this. Such a practice hinders nature, provokes disease, and prevents the coagulation and consolidation of the wound (Gordon, 1959). Theodoric's teachings were accepted by Henri de Mondeville, surgeon to Philip Le Bel, King of France, but the forces of tradition were too strong, and a further 600 years were to elapse before the work of Pasteur was to confirm the observation of Leeuwenhoek, the inventor of the microscope, and others who claimed to have seen minute organisms or particles, the existence of which had first been suggested by Fracastorius in 1546.

Pasteur showed that fermentation was due to the contamination of media by micro-organisms and that these could be killed by heat. If further contamination was prevented following sterilization, then putrefaction or fermentation could be prevented.

Lister saw the possibilities of Pasteur's findings in relation to wound infection and believed airborne organisms to be the cause of wound suppuration. In 1867 Lister described the treatment of 11 cases of compound fracture, in which the wounds had been washed with undiluted carbolic acid and then dressed with lint or calico and, to prevent evaporation, covered by a sheet of tin foil, the forerunner of the present-day medicated occlusive dressing. Within a few years he had changed to antiseptic absorbent dressings which consisted of eight layers of carbolized gauze. He later found that carbolic acid "irritated" the wound, and he sought milder antiseptics, but always his thoughts were to prevent the ingress of airborne organisms and to kill by chemical means those organisms that had gained access to the wound. Lister's teachings, which were slow to be accepted in England, stimulated thought throughout Europe. It was soon realized that chemical antiseptics had their limitations and that a more profitable line of attack might lie in the sterilization of all materials coming into contact with the wound.

With the development of the steam sterilizer by Lautenschlager, Schimmelbusch in Berlin was quick to see the advantages of using sterile dressings, and in 1893 he published the results of eight years' successful treatment with steam-sterilized dressings. It was becoming apparent to the more thoughtful that the habit of preparing dressings from old linen, rope, and rags was one of the causes of suppuration, and that to reduce cross-infection dressings should be burnt after use and not washed and re-used. Of those in the nineteenth century who gave much thought and effort to improving wound dressings, the names of Anderson of Glasgow, Gamgee of Birmingham, Mathias, Mayor of Lausanne, Guérin of Paris, and Viktor von Bruns of Tübingen should be remembered. They demonstrated the advantages of carded, scoured, and bleached cotton wool, compared with materials such as oakum, shredded and carded old rope from prisons, workhouses, and ships, charpie (linen thread), and rag and tow (short flax fibres).

Gamgee's work on wound dressings was undoubtedly facilitated by his collaboration with industry. In a letter to the Editor of the *Lancet* in February 1880, Gamgee (1880b) reported further developments on absorbent and medicated surgical dressings: "Since you favoured me by publishing my article (1880a) under the above heading, many cases in the practices of other surgeons, as well as in my own, have proved the perfect comfort and great therapeutic value of the absorbent cotton wool and gauze pad with and without antiseptic and styptic medication. I beg leave through your columns to express regret for sending such scanty specimens to those gentlemen who have applied to me for the materials. The fact is that such has been the demand that it has been impossible to meet it. The difficulty cannot recur as the matter has been taken in hand by the well-known manufacturing chemists of this town, Messrs. Southall Bros. and Barclay." He went on to say that the suggestion to use pads of Gamgee tissue instead of napkins "has been acted on by several accoucheurs who speak of their comfort and purity with approval". This was the beginning of the modern sanitary towel. On February 8, 1880 (Bailey and Bishop, 1946) he gave a lecture at the Queen's Hospital, Birmingham, 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." 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.

Cotton products, particularly cotton wool, gauze, and lint, became the established dressing materials and are still the most widely used. During the First World War, Wright and Fleming demonstrated that the antiseptics available did not control wound infection, partly because they became inactivated by wound exudate and in any case did not penetrate the deeper parts of wounds. During this period the irrigation of wounds with hypochlorites, Dakin's solution, gained favour, while others believed in the exposure of wounds to the air. With improved treatment, the problem of adherency of dressings started to emerge. This resulted from the increased use of dry dressings and, through the control of infection, the diminution of wound exudate, which in the past had kept the dressing wet and prevented adhesion. It now seemed that a porous non-wettable inter-layer was required to separate the wound from the absorbent dressing. Tulle gras, a wide-meshed cotton net, impregnated with soft paraffin wax and balsam of Peru, was introduced by Lumière. This dressing permitted air to reach the wound, and at the same time drainage was possible. Here was the beginning of the non-adherent dressing which, with various modifications, has remained popular to the present day. Recently, some manufacturers have replaced the cotton fabric with a rayon tulle.

In 1935, with the discovery of the sulphonamides, a new attack was launched on the problem of bacterial infection of wounds. These chemotherapeutic agents were able to kill organisms and could be administered either locally or systemically. Gradually their limitations emerged, organisms became resistant, and the patient hypersensitive.

In Germany, from 1933 onwards, increasing attention was paid to the replacement of cotton dressings by paper and cellulose wadding. Research along these lines was undoubtedly influenced by the flourishing cellulose industry and a desire to be independent of cotton, supplies of which were largely controlled by Britain and America. At this time the rayon industry was developing, and the search for new fibre- and film-forming polymers had started.

In 1943 penicillin was discovered. Once more it was thought that at last a chemical agent which would control wound infection and allow wound healing to proceed unhindered had been found. Since the Second World War the emergence of a whole range of resistant organisms has once more blunted the initial enthusiasm.

Those who are particularly interested in the history of wound dressings should consult the very excellent monograph by Bishop (1959), from which some of the information in this introduction has been obtained.

It is not within the scope of this paper to cover the physiology of wound healing, about which there is a considerable literature. Arey (1936) has very ably reviewed some 380 publications on the subject, but it is remarkable that in his comprehensive work there is practically no mention of the influence of dressings on the healing process.

Wound Dressing Studies since 1944

Natural and Synthetic Fibres and Films.—By 1944 a variety of polymers in fabric or film form had become available.

Owens, at the American Association of Plastic Surgeons in Philadelphia in 1944, drew attention to the unsatisfactory nature of mesh gauze 44/40 even when impregnated with a non-irritant grease (Owens, 1946). Non-impregnated dressings caused pain and discomfort, became adherent to the wound and, when removed, caused bleeding and delayed wound healing. Impregnation of the gauze with a greasy base, in an effort to prevent adherence, interfered with the drainage of the wound exudate. His first experiments, to separate the absorbent dressing from the wound, were made with polyamide fabric, but the material used apparently failed in certain respects which he did not disclose. He found that non-delustred 30 denier continuous filament, saponified cellulose acetate fabric, 0·02 in. thick, having a warp and weft count of 114×114, caused minimal irritation to the wound, provided adequate drainage, and prevented the penetration of new blood capillaries into the dressing. Because of the fine weave and small pore size of the fabric, it is necessary to moisten it with normal saline to establish capillary drainage. When the fabric is used on an infected wound with a thick, purulent exudate, the entire dressing should be moistened, *i.e.* the fabric in contact with the wound and the absorbent pressure dressing applied over it. Owens' intention was not to produce a non-adherent dressing, but rather to use the fabric as a separating layer between the wound and the dressing, which would allow drainage but at the same time keep the wound moist and prevent the ingrowth of repair tissue into the dressing. He believed that the use of a smooth, continuous filament in the construction of the fabric reduced friction between the dressing and the wound.

Bloom (1945), when a prisoner of war, used the "cellophane" wrapping from blood transfusion equipment in the treatment of burns and thought that for this purpose it was preferable to tulle gras. The "cellophane" must have been of the water-wettable variety. He stated that "in the more severe cases, the area will begin to steam immediately, showing that water is transuding through the dressing". Cracking of the film at flexures was, however, a disadvantage, and as a wound dressing "cellophane" has not sufficient plasticity and drape. He noted that the burns healed normally under a thin layer of inspissated, purulent serum and that the pain disappeared as soon as the burn was covered with the cellulose film. As far as is known, this was the first time a synthetic, or perhaps more correctly a semi-synthetic film had been used as a porous wound cover.

The first use of a solution of a synthetic polymer as a wound dressing seems to be that reported in 1945 by Marshak. He used a solution of equal parts of isobutyl methacrylate dissolved in toluene as a splint and occlusive cover for full-thickness circular wounds made in the necks of rats and rabbits. The dry film adhered to the surrounding skin and, until it was removed on the eighth day, prevented contraction of the wound. In the animals the solution did not produce a vascular reaction or visible exudate; this was in contrast to man, where he found that when the solution was applied to fresh wounds an excessive, sero-sanguineous exudate resulted. There was no reaction when it was applied 24 hours or more after injury. He stated that "it has been found to adhere and protect the wound for three to four days under conditions (K.P. duty) where a bandage dressing was of little value". He suggested that the plastic solution might have some practical use as a wound dressing, since it did not contract like collodion, and therefore could be used as an encircling dressing.

By this time, non-porous, plasticized polyvinyl chloride and related polymer films were available and were being used mainly for first-aid dressings. The dressings carried a cotton-lint pad and had a continuous-spread adhesive margin. The object of this type of dressing was to exclude liquids and bacteria from wounds and to prevent organisms, which might be present in the wound, from contaminating foodstuffs. This type of dressing is still the most suitable for use in the food industry. The barrier function of the dressing, of course, is dependent on the integrity of the adhesive seal between the dressing and the skin. The principal disadvantage is that, being impervious to water vapour, the horny or keratinized layer of the skin becomes swollen, white, and soggy. This change in the epidermis or outer cellular layer of the skin is due to the uptake of water by the keratin. The water is derived from the wound exudate, the normal, insensible loss of water vapour through the surrounding intact skin, and the secretion of the sweat glands. If the adhesive seal between the dressing and the skin fails, then the dressing pad quickly becomes saturated if the part is immersed in water. With a non-water-vapour permeable dressing film the pad cannot easily dry out.

In 1944 some significant facts and figures were published. Winsor and Burch found that the rate of water-vapour loss from the skin was approximately 234 g. of water vapour/m.^{2} body surface every 24 hours, the relative humidity of the surrounding atmosphere being 50% at 75°F. (23·9°C.). There was approximately a tenfold increase from the floor of a blister raised by cantharides, *i.e.* 2,340 g./m.^{2}/24 hours.

It was shown by Burtenshaw (1945) that the fatty acids of the skin had sterilizing properties. Williams and Miles (1945) showed that the commonest contaminating organism of small wounds was *Staphylococcus aureus*, an organism which frequently resides in the nose.

Bull, Squire, and Topley (1948) carried out experiments with a methoxymethyl substituted polyamide type 66 polymer. A film 0·001 in. thick has a porosity to water vapour of 1,920 g./m.^{2}/24 hours at 40°C., with a differential water vapour pressure across the film of 53 mm. Hg, or a relative humidity of 95%. Taking the figures of Winsor and Burch (1944), such a dressing film has an adequate porosity to water vapour. A major advantage of this film was that the porosity did not depend on physical pores, but rather on the formation of loose chemical bonds between the H^+ and OH^- ions and the polyamide. The film could be sterilized and was an effective barrier to micro-organisms. Studies of the bacterial flora of normal exposed skin of hospital patients and of skin covered by the polyamide fibre dressings showed that *Staph. aureus*, the principal pathogen in wounds, disappeared and that the number and variety of other organisms were reduced.

Schilling, Roberts, and Goodman (1950) carried out a controlled clinical trial in a Manchester engineering factory, using 0·003 in. thick polyamide film dressings and polyvinyl chloride waterproof occlusive dressings of the type approved by the Chief Inspector of Factories. The trial was carefully planned and conducted so as to reduce personal bias to a minimum, a most important point in any trial of wound dressings. As the polyamide film was transparent, these dressings were not disturbed until healing took place, while the waterproof dressings were changed daily after the first three days. The wound was

deemed to be healed when the worker could be allowed to return to his job without a dressing. One hundred and forty-five wounds were treated with polyamide dressings and 129 with waterproof dressings. In the final analysis only those cases were included in which the injury was thought to be healed on a working day other than a Monday. Healing times were as follows: polyamide film, 6·04+ 0·16 days; and waterproof dressings, 8·39 + 0·25 days. They noted that wounds contaminated with oil appeared to heal more quickly than clean wounds. The polyamide dressings did not carry a pad, whereas the waterproof control dressings carried a lint pad. Whether the pads were medicated is not stated. To protect the dressings a cotton bandage was applied. The results of this trial suggested that for minor injuries it was preferable to use a water-vapour permeable dressing. It must be remembered that the polyamide film was also permeable to oxygen and carbon dioxide, and this fact may have some bearing on the results. It was claimed that it was an advantage for the dressing to be transparent, so that the condition of the wound could be seen, thus obviating unnecessary changes of the dressing.

One of the functions of a dressing is to protect the wound from further injury while it is healing, and for this purpose, particularly with first-aid dressings, a pad is required between the film and the wound to act as a shock-absorber. However, recent clinical trials which we have been carrying out suggest that there is considerable friction between the pad and the wound in those situations where movement occurs, for example in the treatment of an injury of a joint; the protective advantage may be offset by the trauma due to friction between the pad and the wound.

It may be that the use of a smooth polyamide film in contact with the wound instead of a lint pad was a contributory factor in the reduced healing time of those wounds treated with this film. The polyamide dressing, however, never became accepted in clinical practice since the film lacked drape and extensibility, was difficult to coat with adhesive, and, when the protective layer over the adhesive was stripped back, the film tended to curl. Further, the polymer is expensive, and this aspect of wound dressings is important when they are to be used for other than experimental purposes. In spite of these criticisms, however, the work with the polyamide dressing was the first well-controlled trial of dressings to be published, and was an important step forward in the evolution of wound dressings.

In 1947 Blaine examined an absorbable alginate product, calcium alginate. Calcium ions will react with the soluble sodium salts of alginic acid to form insoluble calcium alginate. Using this reaction, filament films and foams can be produced. Calcium alginate is absorbed in the tissues, and thus it was thought that fabrics made of this polymer might be useful for wound dressings and for operation swabs, which from time to time are left inadvertently in the patient. A further advantage of alginate products is that they can be sterilized by autoclaving. Their rate of solubility can be adjusted by varying the sodium ion/calcium ion ratio during coagulation of the sodium alginate. In contact with bleeding tissues calcium alginate has a haemostatic effect, possibly due to the release of calcium ions. When calcium alginate fabrics or wool are applied to a wound, dissolution of the structure occurs in the clot, but when drying of the scab takes place a hard mass is formed in which are incorporated the threads from the unaffected fabric. Only when the wound is wet can the unaffected part of the dressing be removed without causing further trauma. This trauma can be prevented when the central mass is moistened with 5% sodium citrate. It has been suggested that the use of a soluble dressing might be an advantage in that, in the early stages of healing, medicaments would be released into the wound. Frantz (1948), using calcium alginate in the form of stockinet gauze, found that with rats and dogs its haemostatic effect was not as great as that of human fibrin foam, oxidized cellulose, and gelatine sponge. He further thought that it was slightly more irritating than oxidized cellulose. At the present time non-medicated, non-absorbable sterile dressings are preferred.

For many purposes an important function of a wound dressing is its ability to absorb wound exudate. This function is dependent on the rate at which the exudate soaks into the dressing and the quantity of exudate which it can absorb. The first function is particularly important when the fabric is being used as a pad on an adhesive dressing, since, if blood is not absorbed quickly, it spreads over the skin to which the adhesive is to be applied. The rate of absorbency may be measured by the sinking test for absorbency described in the *British Pharmaceutical Codex* (Pharmaceutical Society of Great Britain, 1959). In this test 1 g. of the material is compressed to a volume of about 20 ml. and placed lightly by means of forceps on the surface of water at 20°C. It should become saturated and sink within 10 seconds. This test is of value as a laboratory test for the comparison of fabrics, but the viscosity and other properties of wound exudates are variable, and therefore the test cannot indicate the behaviour of fabrics in actual use. Further work is required on this point.

The second factor, which is probably of greater importance, is the quantity of wound exudate absorbed. This, Savage, Bryce, and Elliott (1952)

have defined as the water-retention coefficient of the dressing. They studied the water-retention coefficient of a number of materials, including sphagnum moss, muslin, gauze, lint, rayon, and cotton wool. They found that the water-retention coefficient depended very greatly on the working pressure on the dressing, that is the pressure applied by the bandage or cover over the dressing. It was found that the more random the arrangement of the fibres, the greatest disarrangement being in the wools, the greater the fluid uptake. Sphagnum moss had the highest water-retention coefficient, followed by cotton and rayon wool. These were followed by paper pulp, cellulose wadding, lint, and open gauzes of the B.P.C. and hospital qualities commonly used in Britain. The finer gauzes used in other countries were even less satisfactory. Lint, a dressing material peculiar to British countries, had the highest water-retention coefficient of any woven fabric, the value being largely dependent on the proper raising of the lint. They also studied the pressures produced by a bandage on a dressing. In the experiments, to reduce variables to a minimum, one person applied the various bandages over a small rubber pressure bag attached to the arm. An open-wove bandage applied on a relaxed bare arm, held in a flexed position, produced pressures varying from 19 to 33·5 g./cm.^{2} When the arm was extended and the muscles tensed the pressures were doubled. When a pad of cotton wool was introduced between the skin and the bandage, pressures ranging from 12 to 20g./cm.^{2} were produced, which were again doubled when the arm was extended and the muscles tensed. Using an elastic bandage of the crêpe type, average pressures of 24 g./cm.^{2} were recorded. On extending the arm the pressure values rarely increased by more than 50%, this being due to the elasticity of the bandage. These studies, besides having an important bearing on the water-retention coefficient, once again show how high friction values may be produced between the wound and the dressing.

Heifetz, Lawrence, and Richards (1952) and Heifetz, Richards, and Lawrence (1953) studied the influence of gauze dressings on wound healing in the rabbit and in man. Full thickness wounds, 3 × 3in. (7·6 cm.), were made in the abdominal wall of rabbits and covered by 12-ply 20 × 20 mesh gauze pads. Comparable wounds were made in another set of animals and left uncovered. The dressings were retained in position by elastic adhesive tape. Whether or not the use of the tape made the dressing virtually of the occlusive type is not clear in the report. Macroscopically there was no difference in the appearance of the two sets of wounds until the fourth day, when the covered wound showed a tendency to be moist and encrusted. On the eighth day, however, histological preparations showed that there was increased epidermal proliferation in the dressed wounds. In their experiments in man, 53 non-infected surgical wounds were divided into three groups. Normal gauze dressings, abdominal pad, and tape were used in one group, in a second group the same dressings were used but were removed at 24 hours, and in the third group no dressing was employed. There was no statistical difference between bacterial counts in the three groups of wounds carried out on the first, second, and fourth post-operative days. While such dressings may not keep bacteria out, they do drain a wound and remove organisms and culture media from the wound. They recommended dressings: (1) after an operation in which local anaesthetic agents have been used; (2) for wounds requiring drainage; (3) for wounds through the scar of a previous operation; (4) for wounds in which there is not complete haemostasis; (5) for wounds in which tissues have been roughly handled; (6) when wounds are closed by catgut; (7) when wounds are closed quickly because of the condition of the patient; (8) for wounds in which there is a dead space; and (9) for wounds requiring splinting or which might be subject to trauma. If exudate resulting from infection and tissue damage is likely to ensue following an operative procedure, then an absorbent dressing which presents a large evaporative surface and, at the same time, exerts a suction gradient outwards, is required.

In vitro experiments by Lowbury and Fox (1953) with *Staphylococcus pyogenes* and *aureus*, *Pseudomonas pyocyanea* and micrococci suspended in horse serum showed that after drying there was a drop in the viable count of all the types of organisms, *Ps. pyocyanea* being most susceptible.

Körlof (1954) studied the effects of different types of treatment on wounds in animals infected with *Ps. pyocyanea* and confirmed the beneficial effects of cooling and drying. Standard burns were made on guinea-pigs and inoculated with *Ps. pyocyanea*. The general condition of the animals, their weights, and the healing of the wounds were studied. Eleven groups of 12 male animals were used. A standard 25 mm. diameter burn was made. The coagulated tissue was immediately cut away and the wound inoculated with 0·1 ml. of a 1 : 1,000 dilution of a 24-hour broth culture of *Ps. pyocyanea* recovered from a patient. Some wounds were covered with a dressing consisting of a single layer of 3 mm. mesh gauze impregnated with vaseline and a layer of Gamgee tissue which was covered with oiled cotton wool followed by an elastic bandage. The dressing, for all practical purposes, could be considered an occlusive dressing. The Gamgee was impregnated with one of the following medicaments: polymyxin

B, chlorophyll, "phenacetol-septon", and sodium chloride. One group had what was termed a light porous dressing applied. This dressing consisted of one layer of oiled 3 mm. mesh gauze, a layer of Gamgee and chlorophyll, and an elastic bandage. In another group the burns were left exposed to the air. The lowest mortality rates were in those groups in which the wounds were treated with a light dressing or were left exposed. While *Ps. pyocyanea* was recovered from all the wounds, the organisms were less abundant in the burns left exposed. The condition of the animals, judged by variation in weight, showed that only with the exposure treatment did the animals regain their original weight in 10 to 12 days, whereas with all other methods of treatment the pre-operative weight had not been regained in 30 days.

Another approach to the problem of adhesion of a dressing is the interposition of a non-wettable macroporous plastic film between the absorbent and the wound. Gelinsky (1954) described a dressing, consisting of a woven non-absorbent plastic film, backed by an absorbent. Unfortunately, no details of the dressing have been given. He claims that the smooth surface of the dressing reduces surface trauma. Gelinsky believes that all dressings are a necessary evil and that it is preferable to expose the wound, but at the same time to keep it slightly moist. Rice and Vogt (1955) used a 0·0025 in. polyester film, having 200 perforations/in.^{2}; the diameter of the perforations varied between 0·008 in. and 0·04 in. This film was backed with an absorbent. The combination of film and absorbent is known as the Telfa dressing. A variety of traumatic and surgical wounds were dressed. Although no control experiments with conventional dressings were reported, they thought that the dressing kept the wounds at least as dry as conventional dressings. In the presence of wound infection the perforations were not large enough. In certain wounds with considerable serous exudate because of adhesion, moistening of the dressing was required before it was removed on the fourth day.

Gray and Jones (1956) used a similar type of dressing as an intranasal pack. Thirty-two patients were treated, 16 with the polyester film dressing and 16 with vaseline gauze. In none of the 16 cases was there adhesion of the pack, visible disturbance of the tissues, or complaints of pain. These findings contrasted with those in which vaseline gauze had been used. Fourteen patients had some bleeding or adherence of the pack, four patients had a firmly adherent pack which took from one to three days to remove, and in one case cartilage and mucous membrane were dislodged. The disadvantages of the Telfa dressings were that the packs were easily dislodged and would not pack into nooks and crannies; in other words, they were too slippery and lacked flexibility.

Gillman, Hathorn, and Penn (1956), using a polyester film absorbent dressing of the Telfa type, found that in full-thickness wounds made in the flanks of rabbits, both epithelial proliferation and repair of the deeper tissues were delayed when compared with control wounds dressed with tulle gras. Why the apparent difference between man and the animal?

In further studies, Gillman and Hathorn (1957) found that with full-thickness wounds in rabbits a non-perforated film promotes epithelial growth but suppresses granulation tissue formation. No details are given as to the type of polymer. It could be that one of the factors responsible for this strange difference between the polyamide film dressing and the Telfa dressing is the lower wound temperature that could be expected with the polyamide dressing. On the other hand, it may that the type of polyamide used in this work was permeable to water vapour and that the environment beneath the dressing was more suited to epithelial proliferation.

Although the type and severity of wounds vary widely and the dressings may be required for a variety of reasons, the various studies of wound dressings have made it possible to specify the properties which the "ideal" all-purpose wound dressing should possess (Scales, 1954).

1. It should have a high porosity to water vapour, preferably at least 1,400 g./m.^{2}/24 hours, measured at 37°C. with a relative humidity of 75% (P.A.T.R.A. 1948, tentative standard method).
2. It should not adhere either to blood clot or to granulating surfaces, nor should it allow the penetration of capillary loops. It must, however, absorb free blood or exudate and give "protection" to the wound.
3. It should be a barrier to the passage of micro-organisms.
4. It should be capable of following the contours around a joint during movement, for example, flexing of a finger.
5. It should be unaffected by domestic or industrial fluids, for example, detergents and oils.
6. It should not produce a tissue reaction when applied to normal skin or granulating surface, nor a state of allergy or hypersensitivity.
7. It should be non-inflammable.
8. It should be capable of being sealed to the skin.
9. It should be capable of being sterilized.
10. It should be available at a low cost.

In an attempt to meet the above criteria the Medical Research Council assisted work at Stanmore aimed at developing a micro-porous

water-vapour permeable dressing which would be particularly useful for the treatment of minor injuries. The function of this dressing was to create a suitable environment for healing to occur; to protect the wound from injury while healing was occurring; to absorb exudate; and to prevent infection of the wound. This development was made possible only by close collaboration with industry. Following a number of clinical trials, an adhesive, micro-porous, plasticized polyvinyl chloride film dressing, carrying a cotton stockinet pad, was developed, which went some way towards meeting the criteria for an ideal dressing. This dressing, now known as Airstrip, allows the passage of 1,400 to 1,800 g. of water vapour/m.^{2}/24 hours at 37°C. with a water-vapour pressure gradient across the film of 46·6 millibars.

Clinical trials carried out with this dressing, using a standard polyvinyl chloride waterproof occlusive dressing carrying the same type of pad as a control, showed that there was a considerable reduction in the bacterial count on normal skin covered by the porous dressing at the end of three days. In the treatment of wounds, no *Staph. pyogenes* was isolated from any wound swabbed initially or at any time during healing in those cases treated with the porous dressing. It was recovered from five cases treated with the occlusive film dressing. In 18 finger wounds treated with the micro-porous dressing the average healing time was 4·1 days, whereas in 15 wounds treated with the occlusive dressing the average healing time was 6·3 days (Scales, Towers, and Goodman, 1956). While this dressing allowed the drying of the wound, this advantage was partially offset by the adhesion of the pad to the wound. This was particularly evident in those areas of the body which did not get wet. In the case of occlusive dressings, which prevented drying, the advantage of minimal adhesion was offset by undesirable bacteriological changes. The problem of adhesion is greatest in the abrasion or graze, where there is an area of epidermal loss.

Baron (1956a), in an extensive series of animal experiments starting in 1948 using standard ring wounds, studied the effects of various types of cotton, rayon, and wool woven and knitted dressings on partial- and full-thickness wounds. The outline of the wound is marked by two concentric blades, the depth of the wound being governed by the depth of the tissue dissected out between the two ring cuts. In his full-thickness wounds, bridges of connective tissue are left between the central island and the normal skin. He assessed the influence on healing of these materials by measuring the rate of reduction in area of the wound and by the change which occurred in the central island. He has not been particularly concerned with the histological and bacteriological aspects of the problem. In the wounds in which there was minimal loss of fibrous tissue, *i.e.* partial-thickness wounds, there was no oedema of the wound edges, no gross exudate, infection or tissue loss, and wound healing occurred by the end of the second week. In full-thickness wounds not treated with dressings with 90% tissue loss, the remaining 10% being the fibrous tissue bridge, lying in a cranio-caudal direction (head-tail), the results were very different. After 24 hours there was considerable oedema of the wound edges, with exudation under the scab. Subsequently, wound infection occurred with loss of tissue in the central island, 20% of which finally became necrotic. At the end of the second week there was granulation tissue in the floor of the wound which became covered by epithelium after 18 to 20 days. If the wounds with a 90% loss of tissue were treated with an eight-layer gauze dressing, necrosis of the central island occurred in only 5% of the wounds. When the undressed wound was covered with a cellulose film, a purulent wound secretion with oedema of the wound occurred. However, if eight layers of gauze were applied, only a serous exudate resulted without wound oedema. Baron found that "cellophane" dressings delayed wound healing when compared with the gauze dressings. He believes that suction, absorption, and compression must all act simultaneously, and this can be achieved only by the use of fabrics, the degree of the beneficial effect depending on the construction of the fabric and the number of layers used. To protect the wounds on the guinea-pig, he used bilateral Perspex cups held in place by encircling elastic bands. In some of his experiments he studied the effects of occlusion by not perforating the cups; in this way he created what he called the "moist chamber" effect. As a result of his work he devised a dressing having a duplex construction in which the warp thread is highly twisted, whereas the weft thread is not highly twisted but of substantial bulk. This dressing is made from bright rayon staple fibre. The weave of the fabric is relatively coarse to allow ventilation of the wound and the passage of wound exudate. This dressing has a relatively high volume uptake, and, after the dressing is wetted by the exudate, the highly twisted fibres contract and tend to lift the dressing clear of the wound. Baron stresses the effects of gravity on tissue and exudate, which gravitate to the most dependent part of the wound, and states that compression dressings prevent such an occurrence. Ring wounds dressed with bleached cotton dressings healed more slowly than those dressed with rayon. He believes (Baron, 1956b) that optical bleaches, a number of which have been used on wound textiles in Germany, are harmful. The *British Pharmaceutical Codex* 1959

does not permit the use of optical bleaches in wound dressings.

Baron summarized his work as follows: 1. The material from which a dressing is made has a decisive influence on wound healing; 2. rayon is preferable to cotton because it has more rapid absorption and is less irritative to the wound, as judged by the amount of exudate and healing rate; 3. thicker yarns are more satisfactory than thinner yarns; 4. generally there is a lower mortality rate in guinea-pigs with rayon dressings than in those with cotton dressings; and 5. a wound dressing should be applied as soon as possible after injury.

Gelinsky (1957) has somewhat different views from Baron. He has stated that Baron's work can only be taken as an indicator of the approach to the problem in man, since his method of holding dressings in place by capsules secured by elastic bands is liable to cause interference with the blood supply to the wound. It is for this reason that Baron has found his thick dressings more favourable, because they allow the "edge pressure" of the capsule to be more evenly distributed. Gelinsky believes that the high mortality rate with cellulose film was the result of using a film only 0·1 mm. in thickness. Gelinsky, however, agrees with Baron on the importance of wound drainage. He believes that a dry dressing is required for haemostasis, and that after six to 24 hours the dry dressing should be discontinued as it promotes a viscous bulky secretion; if a dressing is required after this time, it should be of such a construction as to keep the wound in a "moist" condition, that is, it should prevent excessive drying out of the wound. In this way the white cell layer is not desiccated. The type of dressing which he prefers consists of a woven or perforated plastic film with a fibrous absorbent backing.

Hoffmeister (1959) compared 16 layers of hospital gauze with one layer of Texatraum (Baron's dressing) in the treatment of clean surgical wounds. Two groups, each of 200 patients, were treated. The dressings were changed at five days and thereafter at three-day intervals. There were eight cases of wound infection with the hospital gauze and five cases with Texatraum. Further, Baron's dressing could not be classed as a non-adherent dressing.

Solution and Spray-on Dressings.—Since 1952 a number of reports have appeared concerning the advantages and disadvantages of film-forming polymers which can be applied with a swab or as an aerosol spray directly to the wound. It is probably most convenient to consider this type of dressing as a rather special entity. Their place in wound treatment has now become very much clearer.

Olow and Hogeman (1953), reporting on an acrylic resin solution, Nobecutane, found that the permeability of a 100 μ film (0·1 mm.) to water vapour was of the order of 140 g./m.^{2}/24 hours at 32°C. To apply a film of consistent thickness is, of course, very difficult, and either too thick or too thin a film, with small pores in it due to bubbling and evaporation of the solvent, can easily occur. They found that the solution had self-sterilizing properties.

They studied in rabbits the healing rate of aseptic sutured wounds, aseptic open wounds, and third-degree burns treated with the polymer dressing alone. They compared the healing rate of the sutured and open wounds with similar wounds treated with gauze dressings, while in the case of the third-degree burns the control wounds were left undressed. The details of the gauze dressing are not given. With the aseptic sutured wounds they found little difference in the rate of healing on either side, except that the epithelium on the side treated with the plastic solution was possibly slightly thinner than that found under the gauze dressing. The tensile strength of the wounds dressed with the polymer appeared to be about 15% lower than in the wounds dressed with the gauze. There was no evidence of infection under the plastic film, whereas under the gauze they found a membrane consisting mainly of white cells, covering almost the entire wound. With third-degree burns no difference in the rate of healing could be demonstrated. However, in clinical practice they found that, when treating skin-graft donor sites, it was difficult to maintain the seal between the film and the skin because of bleeding, whereas with burns there was an accumulation of exudate under the film and subsequent infection.

Wallgren (1954) reported on bacteriological studies and clinical trials with Nobecutane. He found that the solution was sterile and that a film could be prepared, the thickness of which he did not state, on culture plates which would prevent the passage of micro-organisms. He used the polymer as the only dressing in 1,500 operations on children up to 15 years of age. The dressing was applied to the body either by means of a swab or from an aerosol can. There were no cases of infection or delayed healing. He found that in the treatment of skin-graft donor sites and burns it was not a suitable dressing for the same reasons as were given by Olow and Hogeman. He considered that the dressing was superior to all other dressing methods used previously in clean paediatric surgery.

Rob and Eastcott (1954), describing their findings in the treatment of 200 clean operation wounds in man, which had been dressed with a plasticized acrylic polymer resin, Nobecutane, stressed the need for absolute haemostasis, otherwise the exudate lifted the film. In addition, the skin must be

absolutely dry to maintain the seal. If the wound is to be drained, a textile absorbent dressing must be applied to the area near the drain, while the rest of the wound may be covered with the plastic film. Only one of their 200 cases became infected. The spray-on dressing was found particularly valuable for wounds of the face and scrotum, situations in which it is difficult to apply traditional dressings. They estimated that by using spray-on dressings the cost of dressing clean surgical wounds could be reduced by 20%.

Ekengren (1954) studied the use of the spray-on dressing, Nobecutane, in Korea. The polymer was used as a pre-operative skin cover to provide a sterile field. The wounds were closed with steel sutures and then sprayed with the resin. Approximately 2,640 wounds were treated in this manner, including 438 United Nations Forces members who had sustained war injuries. He found that because the steel sutures tended to project through the film, abdominal wounds had to be covered with a binder and limb wounds with an elastic dressing. Although this was an uncontrolled clinical trial, the incidence of infection seemed far less than with other types of dressings. Infestation of the operation site with fly-larvae, which had been a problem previously because of the hot, humid climate, did not occur. The dressing prevented a patient from probing his wounds with dirty fingers and protected normal skin from the secretion of discharging wounds. Ekengren also made the point of the reduction in cost of the dressing of clean wounds. In hot climates and for emergency work the spray-on dressing seems to offer a number of advantages. Unlike the adhesive dressing, the solution dressing is not subject to deterioration during storage, and there is a considerable saving in bulk and weight compared with the traditional types of dressing. A disadvantage with this type of dressing can be a faulty valve in the aerosol container, which allows evaporation of the propellant.

Randall and Randall (1954) stated that the most important indicator of the efficacy of a dressing is the rate of epithelization. They pointed out that the healing of a wound is influenced by many variables, such as the depth and extent of the wound, the amount of damaged tissue, contamination, active infection, and the condition of the patient. All these are difficult to evaluate clinically, but by using laboratory animals of an inbred strain, standard wounds can be made which reduce variables to a minimum. They believed that the skin of the mouse was a good indicator, since partial-thickness wounds soon become converted into full-thickness wounds. Partial-thickness abrasion wounds, 2 × 3½ cm., were made on the backs of 16 g. mice with a razor, and various dressings and medicaments were applied. They made only one wound on each animal, and no control dressing or medicament was used. One week later the animal was sacrificed. They found that the use of a fabric dressing alone or with a medicament was preferable to the exposure treatment. One of the dressings they used was a polyvinyl chloride co-polymer with other additives, known as Aeroplast. They found that this dressing caused severe collapse of the mice, an effect not reported in larger animals, including man. They made the point that it is not possible to estimate by inspection the progress of wound healing under a transparent dressing and that histological examination is always necessary. One of the disadvantages of the mouse is that the skin of certain rodents, notably the mouse, rat, and rabbit, has a regular cycle of physiological activity, and in the mouse this cycle takes 30 days. It is thus exceedingly difficult to study the effects of wound dressings unless a control is used on each animal and a very great number of animals is employed.

Choy, reporting in 1954 on the treatment of 50 patients with polyvinyl chloride and acetate co-polymer solution, 11 first- to third-degree burns, eight donor skin-graft sites, and 31 surgical wounds, claimed that there was no retardation in healing rate; that the film dressing was able to maintain the sterility of clean wounds; that the film could be easily applied and removed; and that the dressing was transparent.

However, the dressing should not be used on infected wounds, otherwise pocketing of pus occurs.

Giles (1956) treated in a military hospital 48 cases of minor surgery and 60 cases of minor injuries with the acrylic polymer solution Nobecutane. In 12 patients haemorrhage occurred within the first 12 to 24 hours and a firm dry dressing had to be applied. In nine patients, who suffered minor injuries and whose wounds were contaminated with dirt, clinical infection subsequently developed.

Wallgren (1957) studied the self-sterilizing and bacteriostatic properties, bacterial permeability, and the effect on the bacterial flora of intact skin of five film-forming polymer solutions in common use at that time: Aeroplast, a polyvinyl chloride and acetate co-polymer; Bonoplast, an acrylic polymer; Nobecutane, an acrylic polymer with tetramethyl thiuramide disulphide; Newskin, a solution of pyroxylin and camphor; and Portex plastic skin, a methyl ester of acrylic polymer.

With the exception of Bonoplast, which is no longer available, all the solutions were self-sterilizing after 15 minutes, when 600 million organisms were inoculated into 1 ml. of the solutions. The organisms used were *Proteus vulgaris*, *Pseudomonas aeruginosa*,

Escherichia coli, and four different strains of *Micrococcus pyogenes*. The bacteriostatic properties of the films were investigated by half covering blood-agar plates with the various solutions. The plates were incubated for 24 hours at 37°C. All the films inhibited growth to a varying degree.

Using a suspension of 600 million organisms/ml., 2 ml. was spread on the surface of plastic films which had been made on blood agar plates according to the makers' instructions. After removal of the film at 24 hours, followed by re-incubation, growth was obtained in the areas originally covered by the films, showing that pores of at least 0·8 to 1·0 μ in size existed in the films. If complete impermeability to bacteria is required, films must be prepared by applying a number of coats of the solutions in excess of the manufacturers' recommendations. The thicker the film, the lower its porosity to water vapour and the less its flexibility.

Wallgren found that applications of Aeroplast, Bonoplast, Nobecutane, and Newskin to the normal skin of patients reduced the bacterial count after 24 hours. His report also gives his clinical experience with plastic film dressings in the treatment of more than 4,500 patients over three years. He claimed that the incidence of infection was below the 3 to 5% found in normal sterile surgery. He did not give an actual figure. He believed that the film dressings had a field of use in the treatment of clean surgical wounds. If there is a possibility of infection with bacteria, traditional fabric dressings should be employed, which will permit drainage.

Heite and Ludwig (1959), in a comprehensive review of the work carried out with film-forming polymer dressings, concluded that there was a limited use for the spray-on dressing in the treatment of dry, clean operation wounds and that in these cases the dressings could be left undisturbed for 14 days or more. They also have a place in the protection of normal skin from various wound and body secretions and for some applications in dermatology.

The use of fabrics in conjunction with these solutions has also been advocated, but the disadvantage of rigidity and loss of transparency of the film seemed to offset any slight advantages gained in other ways. The limited permeability to water vapour, the prevention of drainage of wound exudate, and the impossibility of using these films if complete haemostasis has not been achieved, limit their use. Providing, however, these contra-indications are borne in mind, the spray-on polymer dressing of the Nobecutane type is ideal for clean, surgical incisions and is probably the most suitable dressing to use. In areas subject to friction or weight-bearing, the film should be covered with a gauze or cotton wool pad held in place by a conforming bandage.

From what has been said so far, it is apparent that there is still a considerable difference of opinion regarding the methods of treating wounds and the choice of materials. One thing, however, is certain: wound dressings are required to absorb wound exudate and to protect the wound.

Our experience, when conducting clinical trials, has shown that many of the beneficial therapeutic effects of certain dressings are vitiated by the damage caused to a healing wound when removing an adherent dressing. It is very difficult to study the adhesion of dressings by means of human clinical trials, since the wounds vary in extent, depth, situation, and bacterial flora. It is rarely possible to have a control dressing on the same patient and to carry out a biopsy of the wound to follow the progress of healing. Adhesion of wound dressings is really a problem of the adhesion of two surfaces by a glue, the exudate from the wound. One of the functions of a wound dressing is to be absorbent, and to achieve this a wettable and highly porous structure is required, but it is just such a structure which provides the ideal surface for adhesion. The other surface is a living, changing surface which adds tissue fluids to the adhesive at a diminishing rate for many hours. The composition of the adhesive will vary according to the cellular elements present, and its viscosity may be affected by the proteolytic enzymes of the patient or by bacteria. At one time we thought that the relative adherency or non-adherency of dressings could be determined in the laboratory by drying human reconstituted serum in contact with various dressings, but only limited information can be obtained by this method (Scales and Winter, 1961). To try to confirm the laboratory findings, the materials tested have been used as wound dressings on the domestic pig. This animal was chosen in preference to a small animal, such as the rat, guinea-pig, or rabbit, because it has a broad expanse of skin which can be effectively depilated; upwards of 12 large dressings can be put on at the same time, and the dressings can be protected with a cage. Changes of posture do not disturb the dressings as on a small animal. The skin is morphologically similar to that of man, and there is evidence that the mode of wound healing is also similar.

Hartwell (1955) stated that only in the domestic pig, which is an animal seldom used in wound research, did he find histological observations of sub-epithelial wound healing by first intention, essentially similar to the histological observations he had made in human wounds healing primarily.

One inch square partial-thickness wounds 0·015 in. deep were made on the backs of young pigs, approxi-

mately 50 lb. (22·6 kg.) in body weight, which had been depilated three days previously. Sterile dressings were carefully put over the wounds and held in place by a ring of porous adhesive plaster which permitted the effective part of the dressing to be exposed to the atmosphere. The dressings were protected by a cage held on the pig's back by elastic straps. Ten wounds were made on each pig; five were dressed with one of the materials under test and five with cotton lint as controls. The dressings were changed daily. Since each material was compared with cotton lint, all materials could be compared with one another. The results are summarized in the Table.

TABLE

RATIO OF ADHESION OF VARIOUS DRESSINGS WHEN COMPARED WITH COTTON LINT

A	Cotton stockinet	0·6
B	Cotton lint	1·0
C	High- and low-twist rayon fabric	1·1
D	Woven rayon and cuprammonium strip film dressing	1·3
E	Rayon lint	1·3
F	Tulle gras	1·3
G	Open-mesh continuous filament rayon dressing	1·5
H	Cellulose absorbent enclosed in perforated polyester tube (0·15 mm. holes)	1·6
I	Saponified cellulose acetate fabric	1·6
J	Cellulose absorbent enclosed in perforated polyester tube (0·65 mm. holes)	1·7
K	Impregnated acetate fabric	2·0
L	Triacetate fabric	4·1

It was found that cotton lint and stockinet are the most suitable of the conventional materials. The fact that there were more adherent dressings with the rayon lint than with the cotton lint (1·3 : 1) may be due to the fact that the rayon lint was produced from continuous-filament fabric. Histological studies of wounds from which adherent dressings were removed showed that damage was done to the delicate regenerating epidermis due to fibres becoming embedded in the exudate. A dressing can be removed without damage to the wound only if the bond between the exudate and the epidermis is weakened by normal keratinization at the upper layers of the epidermis and when the epidermis becomes anchored by its downgrowths to the dermis. It was estimated that the completion of epithelization in the partial-thickness wounds was delayed about three days by the use of a cotton-lint dressing which was changed daily. The ratio of adhesion from the Table was determined from the number of adherent dressings. Since all the dressings were adherent to the serous exudate, what factor is responsible for the difference in the adhesion ratio? We believe that it is the different constructions of the dressings affecting the rate at which the exudates dry which is the decisive factor in adhesion. Construction also influences the volume uptake of the dressing and its ability to maintain the correct environment for the maximum rate of epithelial proliferation.

To study the effects of dressings further, it has been found necessary to determine the healing rate of partial-thickness wounds, which are allowed to heal without a dressing, on the domestic pig. The rate of epithelial regeneration in a wound can only be studied by histological methods. The method of estimating the rate of wound healing by planimetry is inaccurate and unreliable, since a scab is formed which is not transparent and wound healing proceeds beneath it. Working with aseptic superficial wounds in the skin of the pig, Winter (1962) has found that by keeping the wounds moist under a polythene film, epithelization of the denuded surface is about twice as rapid as when the wounds are exposed to the air. The explanation for this seems to be that the base of the wound becomes dehydrated by exposure and the regenerating epidermis has to migrate along a plane in the dermis where the conditions are correct for the life of the cells. The leucocytes or white cells are trapped in the dehydrated layer and form with the exudate the normal scab which prevents the ingress of dirt and micro-organisms and protects the delicate cells from dehydration. By covering the wound with a polythene film, dehydration is prevented and the epidermis is able to migrate over the cleanly-cut base of the wound faster than it can pass through the dermis in the wound exposed to the air. Fortunately, the pig appears to have a high resistance to infection compared with man, and therefore the need for rapid concentration of the exudate and formation of the normal scab may not be so essential.

If all wound dressings of the absorbent type (and in the treatment of many types of wounds they have to be absorbent) adhere to wounds, then obviously it is best to make use of this property and to use a fabric which is sufficiently weak not to disturb the exudate when the bulk of the dressing is removed. It is possible to reduce the tensile strength of fine-weave acetate fabrics artificially to a value which permits a dressing to be removed, leaving behind the part incorporated in the scab.

It seems that a dressing must be a compromise. Initially it should absorb wound exudate for in this way bacteria are removed from the wound; it should permit evaporation of fluid in order to allow concentration of the exudate which in turn retards bacterial growth; and the dressing must be of such a construction that its removal does not disturb the eschar beneath which the repair process is taking place. To achieve this the layer of the dressing in contact with the wound must have a low tensile strength, probably in the region of 100 g./12·5 mm. width.

Conclusion

Looking back on the history of surgical dressings, we have seen how progress has taken place in a series of discrete steps, often with many barren intervening years. The stimulus for each new advance has been some new thought about wound treatment, some new knowledge about the wound-healing process itself, or the development of some new class of material in another field. In this century we have a whole host of new materials. We are able now to define the problems associated with wound dressings more clearly than ever before. I believe it is essential to develop a standard method of assessing wound dressings. For this we must have an internationally agreed standard dressing which can be used as a control dressing in all animal and human work. There are certain anatomical variations and differences in physiological activity of the skin of the mouse, rat, guinea-pig, and rabbit which make the interpretation of experimental findings in relation to man very difficult. The only suitable animal with a skin morphologically similar to man is the domestic pig. A number of wounds can be made on one animal which can be examined histologically at various times during healing. In an assessment of wound dressings, three types of wounds should be used: partial-thickness excisions; full-thickness excisions; and third-degree burns. The influence of a dressing on wound healing can be judged only by histological examination of the wounds. While this method of assessing a wound dressing might appear costly and time-consuming, it would allow an international comparison of wound dressings which would be of benefit to the patient, to industry, and, in many countries, to the national economy.

In an effort to help and stimulate research, the International Rayon and Synthetic Fibres Committee has sponsored a survey of literature concerned with wound healing and dressing. I have been most fortunate in having access to the excellent abstracts that Dr. L. J. M. Laurent has made.

REFERENCES

Arey, L. B. (1936). *Physiol. Rev.*, **16**, 327.
Bailey, H., and Bishop, W. J. (1946). *Notable Names in Medicine and Surgery*, 2nd ed., p. 93. Lewis, London.
Baron, H. (1956a). *Arzneimittel-Forsch.*, **6**, 277.
—— (1956b). *Berufsdermatosen*, **4**, 29.
—— (1957). *Reyon Zellwolle und andere Chemiefasern*. Informationsstelle, Frankfurt.
Bishop, W. J. (1959). *A History of Surgical Dressings*. Robinson and Sons, Chesterfield.
Blaine, G. (1947). *Ann. Surg.*, **125**, 102.
Blakiston's Illustrated Pocket Medical Dictionary (1952). 1st ed., ed. N. L. Hoerr and A. Osol. Blakiston, New York.
Bloom, H. (1945). *Lancet*, **2**, 559.
Bull, J. P., Squire, J. R., and Topley, E. (1948). *ibid.*, **2**, 213.
Burtenshaw, J. M. L. (1945). *Brit. med. Bull.*, **3**, 161.
Choy, D. S. J. (1954). *A.M.A. Arch. Surg.*, **68**, 33.
Ekengren, A. (1954). *Nord. Med.*, **51**, 854.
Frantz, V. K. (1948). *Ann. Surg.*, **127**, 1165.
Gamgee, S. (1880a). *Lancet*, **1**, 127.
—— (1880b). *ibid.*, **1**, 308.
Gelinsky, E. (1954). *Zbl. Chir.*, **79**, 1354.
—— (1957). *Bruns' Beitr. klin. Chir.*, **195**, 160.
Giles, K. W. (1956). *Brit. med. J.*, **1**, 727.
Gillman, T., and Hathorn, M. (1957). *Transplant. Bull.*, **4**, 65.
——, ——, and Penn, J. (1956). *Plast. reconstr. Surg.*, **18**, 260.
Gordon, B. L. (1959). *Medieval and Renaissance Medicine*. Philosophical Library, New York; Peter Owen, London.
Gray, G. H., and Jones, H. W. (1956). *Plast. reconstr. Surg.*, **17**, 471.
Hartwell, S. W. (1955). *The Mechanisms of Healing in Human Wounds*. Thomas, Springfield, Illinois.
Heifetz, C. J., Lawrence, M. S., and Richards, F. O. (1952). *A.M.A. Arch. Surg.*, **65**, 746.
——, Richards, F. O., and Lawrence, M. S. (1953). *ibid.*, **67**, 661.
Heite, H. J., and Ludwig, M. (1959). *Münch. med. Wschr.*, **101**, 415.
Hoffmeister, H. (1959). *Med. Klin.*, **54**, 1243.
Körlof, B. (1954). *Acta chir. scand.*, **107**, 244.
Lister, J. (1867). *Lancet*, **2**, 353.
Lowbury, E. J. L., and Fox, J. (1953). *J. Hyg. (Lond.)*, **51**, 203.
Marshak, A. (1945). *Proc. Soc. exp. Biol. (N.Y.)*, **58**, 63.
Olow, B., and Hogeman, K. E. (1953). *Transactions of the Meeting of the Northern Surgical Association in Gothenburg*.
Owens, N. (1946). *Surgery*, **19**, 482.
P.A.T.R.A. (1948). *Packaging Research Report No.* 2. Printing, Packaging, and Allied Trades Research Association.
Pharmaceutical Society of Great Britain (1959). *British Pharmaceutical Codex*, 7th ed. Pharmaceutical Press, London.
Randall, P., and Randall, R. J. (1954). *Plast. reconstr. Surg.*, **14**, 105.
Rice, R. H., and Vogt, P. R. (1955). *Northw. Med. (Seattle)*, **54**, 162,
Rob, C. G., and Eastcott, H. H. G. (1954). *Brit. med. J.*, **2**, 17.
Savage, R. M., Bryce, D. M., and Elliott, J. R. (1952). *J. Pharm. Pharmacol.*, **4**, 944.
Scales, J. T. (1954). *Trans. Ass. industr. med. Offrs*, **4**, 69.
——, Towers, A. G., and Goodman, N. (1956). *Brit. med. J.*, **2**, 962.
——, and Winter, G. D. (1961). In *Wound Healing. Proceedings of a Symposium 12/13 November 1959, London*, ed. D. Slome, p. 54. Pergamon Press, Oxford.
Schilling, R. S. F., Roberts, M., and Goodman, N. (1950). *Lancet*, **1**, 293.
Wallgren, G. R. (1954). *Ann. Chir. Gynaec. Fenn.*, **43**, 279.
—— (1957). *Acta chir. scand.*, **112**, 161.
Williams, R. E. O., and Miles, A. A. (1945). *J. Path. Bact.*, **57**, 27.
Winsor, T., and Burch, G. E. (1944). *Arch. intern. Med.*, **74**, 428.
Winter, G. D. (1962). *Nature (Lond.)*, **193**, 293.