# Skin Health and Stump Hygiene[1]

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Literally the word "hygiene" connotes a state or condition of health. But adequate hygiene, or good health, of the human skin presents a complex problem involving much more than a casual acquaintance with soap and water, the concept which usually comes to mind when hygiene is mentioned. The functional state of our human integument is pretty much taken for granted by most of us. We know that this two-square-yard covering will, in most cases, repair itself in event of local injury, provided infection is avoided. Cheerfully we dissolve it in strong chemical solutions. We broil it in the summer sun until it peels off like old birch bark. We allow it to be rubbed and blistered in tight shoes for vanity's sake. As a nation, we spend millions of dollars on elaborate sun-tan lotions guaranteed to produce in it the beautiful brown of the aborigine and at the same time an equal fortune on lotions and creams which promise to bleach it out to the shade of a sheltered lily.

Even though the skin has remarkable powers of restoration, the conditions of use are occasionally too damaging, or the opportunities for healing between periods of use are too brief for repair and maintenance. In such instances, there may be an acute breakdown of the skin with a severe inflammatory reaction, or the process may be a gradual one, with a progressive deterioration of the skin and a loss of its protective properties. Among individuals in certain occupations, we frequently see both manifestations of such skin reaction. Housewives, mechanics, laboratory workers, and others whose work exposes certain areas of the body, particularly the hands and arms, to prolonged soaking in solutions and solvents, or even in plain water, are prone to recurrent skin irritation and breakdown. In such cases, the chemical and physiological properties of the skin are altered to such a degree that the skin's built-in protective functions are no longer effective. Even in the absence of prolonged soaking, the skin may be injured locally by contact with an irritant, such as a strong acid, or with a sensitizing agent, such as poison ivy.

All of these considerations similarly pertain to amputees who wear some type of prosthesis (Fig. 1), most of which are attached to the stump by means of a snugly fitted socket which excludes circulating air and traps the accumulated sweat against the skin. In the lower-extremity amputee, the effect is aggravated by the added factor of weight-bearing and uneven loading on localized areas of the stump skin, especially in the adductor region of the stump and at other points of contact with the socket rim. Weight-bearing is attended by other mechanical stresses, especially intermittent stretching of the skin and friction from rubbing against the socket edge and interior surface. The latter results in two important and harmful effects on the skin—heat, and abrasion of the skin surface, which in time can, by steady attrition, become highly destructive. Over a long period of time, heat alone may be capable of causing profound changes in the metabolism of living tissues. The stump skin of the amputee is especially vulnerable to the possible irritant or allergic

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action of various materials that compose the socket of the artificial leg.

In this situation, then, the state of health of the stump skin is of the utmost importance in determining whether or not the prosthesis can be tolerated. If the skin cannot be maintained in a good functional condition in spite of daily wear and tear, then the weight-bearing prosthesis cannot be worn, no matter how accurate the fit of the socket may be.

It is the purpose of this article to review some of the basic principles of skin biochemistry and physiology concerned in the maintenance of good hygiene in the stump area. Included are some remarks relative to the use of certain disinfectant agents in skin cleansing, and to some of the natural skin defenses against bacterial invasion, because these topics also are germane to the principal subject with which this article is concerned.

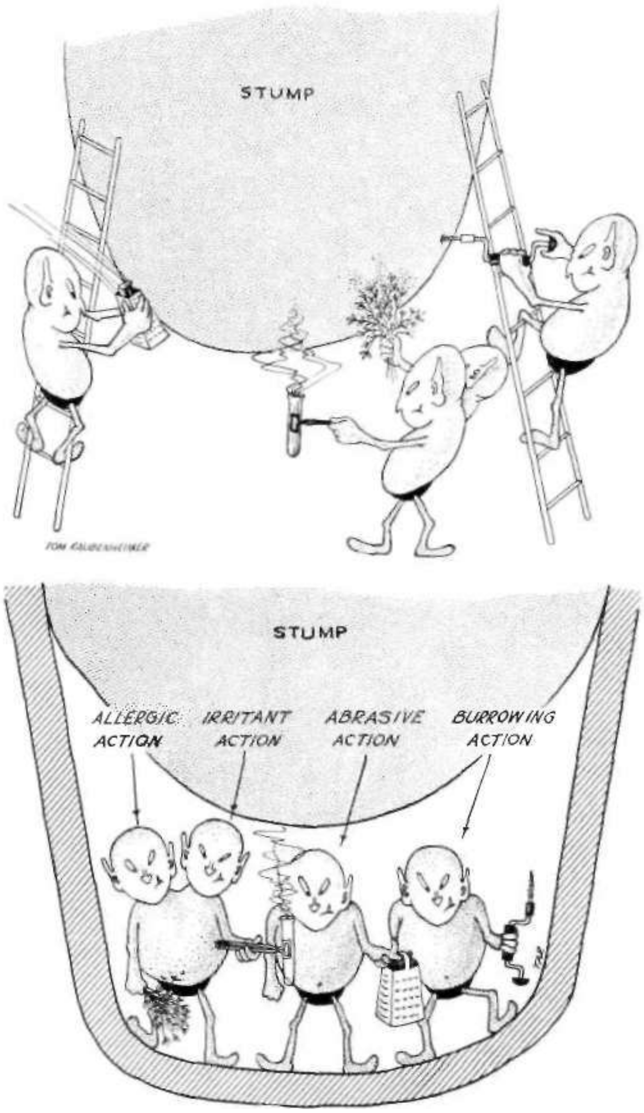



Fig. 1. Injury to the stump skin. The gremlins symbolize some of the common types of damage that may be inflicted upon the stump skin inside the socket of a prosthesis. Injury may be incurred mechanically when parts of the socket abrade the skin or burrow into it. The materials of the socket, coming in intimate contact with the skin, sometimes act as irritants or as sensitizing agents to create a local dermatitis.

### THE SKIN AS A VITAL ORGAN

Man cannot live without his envelope of skin any more than he can exist without his heart or his liver. It might seem at first thought that the cutaneous covering of the body performs about the same function as the leather cover of a baseball —and very little more. Actually, the biochemical and physiological activities of the skin are every bit as complex as are those of the liver. The respiratory rate of the main cellular portion of the epidermis, based on oxygen-uptake studies and glycolysis measurements, has been computed to be from two to ten times as high as the rates of other body tissues.

The skin possesses many properties vital to health and life itself. Of particular interest to us from the standpoint of prosthetic design and use is the part it plays in mechanical support of the soft tissues of the stump. It provides a tough, elastic outer covering with a tensile strength of up to 2 kg. per sq. mm. Furthermore, this covering has a tremendous capacity for repairing itself after injury and for strengthening itself at points of mechanical stress, such as those occurring on the lower-extremity stump in association with the wearing of an artificial limb. A familiar example of this is the "lichenification," or leatherlike thickening of the skin over the ischial tuberosity and in the adductor region of the thigh. We know that "calluses," or localized thickenings of the horny outermost layer of the skin, will form at points of repeated pressure. Sometimes a BB-shotlike condensation of horny material will develop over a pressure point, producing the well-known "corn." All of these thickening processes illustrate the defensive reaction of the skin to abnormal mechanical stress by elaborating a natural cushion from its cellular elements.

Mechanical protection, however, is only one of many important services which the skin performs. Its function in the conservation of water and electrolytes, those ionized salts which constitute an essential part of the body fluids, is nearly as indispensable as is the function of the kidneys. The skin is extremely important in the regulation of the body temperature within relatively narrow limits. It possesses certain important electrical and chemical properties. It is also the first barrier, and one of the chief defenses of the body, against infectious diseases.

Many other properties of the skin that are of less immediate importance to the problem of stump hygiene nevertheless have a bearing on human health and welfare. For example, we rely on the sensory organs of the skin for a good part of our information about the world around us. Through nerve endings at or near the surface, the body receives the outside environmental stimuli of heat, cold, pain, and touch. Also important to health is the role of the skin in maintaining a highly complex system of pigment metabolism and in providing a source of vitamins important for growth and nutrition.

Although there are other vital functions of the skin, those cited serve to illustrate the importance and variety of the services the normal skin performs. Some of these are described at greater length in the following portions of this paper.

## THE ANATOMY OF THE SKIN

Plate I shows in semidiagrammatic form the principal structures of the skin concerned in stump hygiene. The skin is seen to consist of two distinct layers—the epidermis and the dermis, or true skin. These two layers are joined by a system of fingerlike projections, the rete pegs, which protrude down from the epidermis and interlock with the papillae, which project up from the dermis. This device furnishes a relatively large surface area at the dermal-epidermal junction, thus providing a strong bond between the two layers.

The most superficial layer of the epidermis is the so-called "horny layer," consisting of a material called "keratin," which is very similar to animal horn. Scattered over the surface of the skin are numerous deep pockets, called "follicles," into which sebaceous, or oil, glands discharge their contents. From the follicles protrude the hairs of the skin.

Two other types of glands in the skin have an important bearing on the subject of stump hygiene. They are the eccrine, or small sweat glands, which lie in coils near the base of the dermis, and the apocrine, or large sweat glands (not shown in Plate I), which are similarly situated but are more localized in distribution than are the eccrine glands. The watery sweat secretions pass to the surface of the skin by way of the sweat ducts, discharging on the surface through the sweat-duct opening, or pore.

Deep to the dermis lies the subcutaneous zone. Here, cushioned in masses of fat cells, are the large blood vessels which serve the skin. From the arteries, smaller vessels rise, becoming narrower as they branch, until they terminate in fine capillary nets in the papillae of the dermis. Blood from the papillary nets returns again by a venous collecting system to the large veins in the subcutaneous tissue.

## RELATION OF SKIN STRUCTURES TO DISEASE

All of these structures are vulnerable to damage from prolonged wear of a prosthesis. Injury to each different anatomical site results

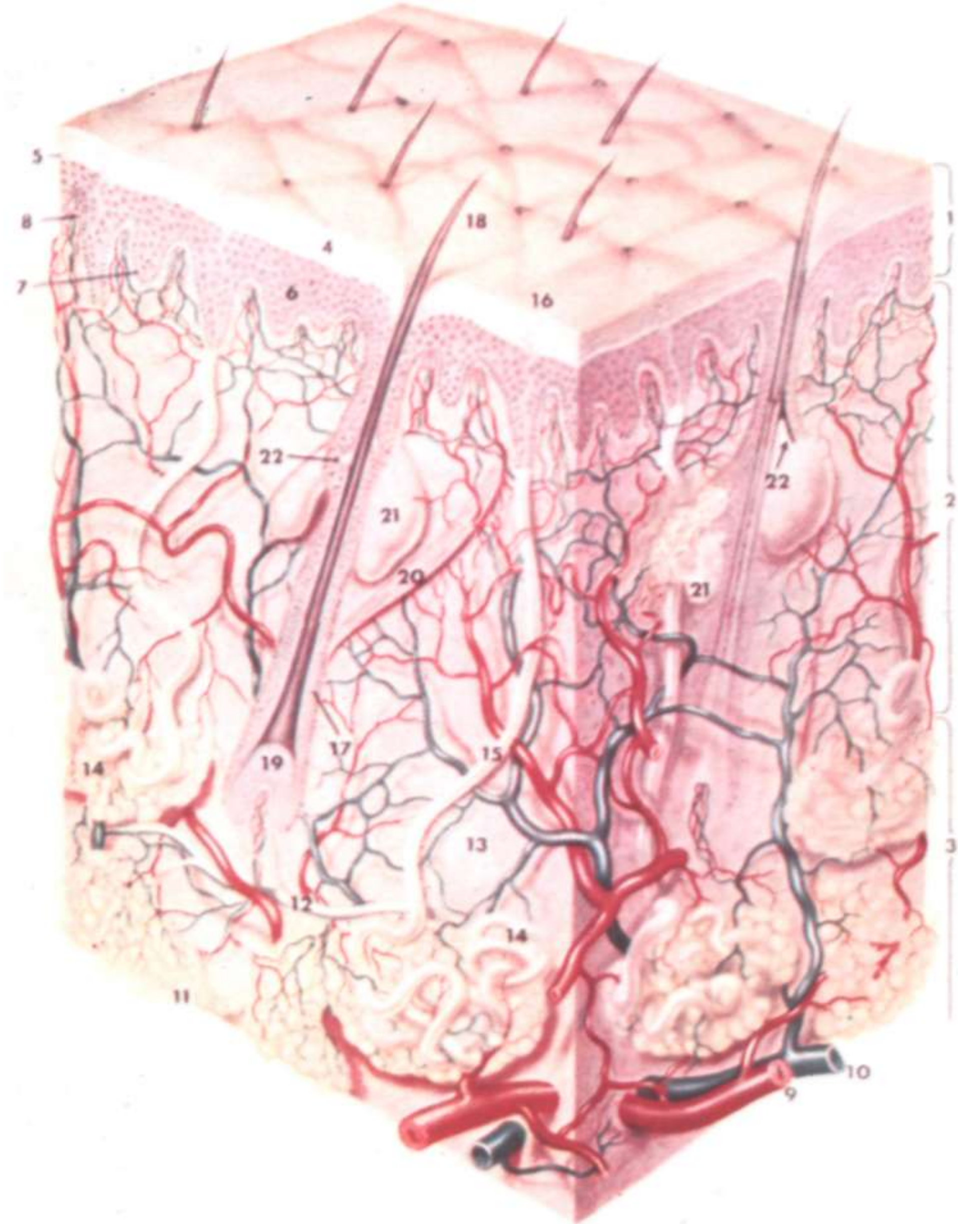



Plate 1. A section of normal human skin. 1, Epidermis; 2, true skin; 3, subcutaneous tissue; 4, horny layer; 5. clear layer; 6, granular layer; 7, germinativc layer; 8, capillary network; *9*. artery; 10. vein; 11. lobules of fat; 12. nerve; 13, corpuscle of Vater; 14. sweat gland; 15, duct of sweat gland; 16, pore of sweat gland; 17, hair follicle; 18, hair shaft; 19, bulb of a hair; 20, arrcctor muscle; 21, sebaceous gland; 22, duct of sebaceous gland. *Courtesy White Laboratories, Inc., KenilKorth, .V. J.*

in a specific disease complex of the skin. For example, excessive heat and moisture may result in a local blocking of the sweat-duct pores. We are familiar with this condition in the form of what is known popularly as "prickly heat," a common malady in warm, humid climates; and the same disorder can occur over stump skin under similar environmental conditions.

Prolonged use of negative-pressure sockets, and to a lesser degree of conventional sockets, may lead to engorgement of the small blood vessels of the skin, resulting in local areas of rupture and extravasation of blood into the surrounding tissues. The dark pigmentation often seen on the terminal end of the stump is the result of this bleeding under the skin. It is usually accompanied by some degree of edema, a state in which there is an abnormal collection of watery fluid in the soft tissues. Thus the skin disorder here is essentially focused in the circulatory system, whereas the previously cited condition of sweat-duct blockage affects primarily one of the glandular systems of the skin. It follows, then, that the over-all hygiene or good health of the stump skin reflects, among other things, the functional state of each of the anatomical components of the skin.

## SKIN GLANDS AND STUMP HYGIENE

In the skin of the lower extremity, three different types of glands produce secretions that are discharged on the surface of the skin. These are the eccrine glands, the apocrine glands, and the sebaceous glands (Plate I). During daily use of a prosthesis, their secretions accumulate inside the socket, where they may become a serious hazard to local stump hygiene.

### *The Eccrine Glands*

The eccrine glands, or small sweat glands, are distributed over the entire surface of the body. They are accessory structures that develop from the epidermis. They are true secretory glands, producing a clear, aqueous fluid, and their functioning is vital to the heat regulation of the body, since these glands are the principal source of sweat. It has been estimated that there are over two million of these glands in the skin of a normal adult and from 500 to 600 per sq. in. over the skin of the thigh and lower leg. It has been reported that the capacity for sweating is considerably less for females than for males. According to Weiner *(23)*, roughly 50 percent of heat sweat comes from the trunk, 25 percent from the head and upper limbs, and 25 percent from the lower limbs.

*Sweat Deposits.* Eccrine sweat is a clear, watery solution containing 0.5 to 1.0 percent of solids. These solids play an important role in stump hygiene because, in the absence of adequate daily cleansing, their accumulation on the surface of the stump and in the socket interior may serve as a source of irritation and to some extent as a culture medium for the growth of harmful organisms. The eccrine sweat solids include urea (in at least twice the concentration found in blood plasma); creatine and creatinine in minute quantities; uric acid; a variety of different amino acids; ammonia; free choline; occasional traces of glucose; lactic acid and lactate (to the extent of more than 2 grams in 90 minutes of heavy physical labor); many of the water-soluble B-vitamins; traces of dehydroascorbic acid; and the minerals sodium, potassium, calcium, magnesium, sulfates, phosphates, and iron. In addition to the sweat solids, there are the secretions of local oil or sebaceous glands, plus a quantity of nitrogenous material made up of keratin shreds and other cellular debris which has been desquamated from the surface of the skin.

This is the residue which collects on the skin and in the socket under normal conditions. If the skin has been damaged by abrasion against the socket wall, or if an eczematous skin condition is present, there may be "weeping" or oozing of serum over the surface, where it mixes with the sweat, oil, and skin debris. This serous material is deposited on the interior wall of the socket, where it dries and sets almost like glue. Successive laminations are added from each day's accumulation, until a considerable thickness may be attained (Fig. 2). Constant wearing and rubbing against the skin may produce a polished, glassy finish on the surface. In the interests of good hygiene, this deposit should be cleaned out of the socket interior regularly.

The innervation of eccrine sweat glands,

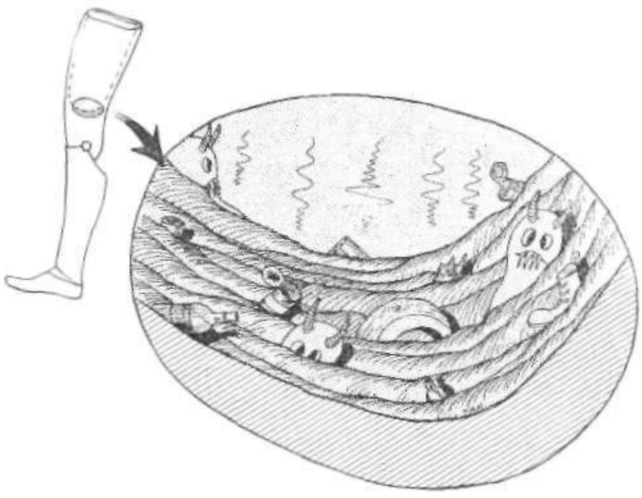


Fig. 2. Debris in the socket. Accumulation of waste in the socket is not favorable to good stump hygiene. Daily waste, consisting of sweat solids, oily secretions, and cellular debris, often combined with serous ooze, is deposited in successive layers that should be cleaned from the socket regularly.

pharmacologically speaking, is parasympathetic or cholinergic. Dale and Feldberg *(10)* demonstrated that the postganglionic nerve fibers liberate acetylcholine at their endings on the receptor cells of the sweat glands. Where excessive perspiration, or hyperidrosis, has been a serious problem, clinical application of this finding has been made by treatment of the patient with an anticholinergic blocking agent to diminish sweating. Drugs like methantheline bromide (Banthine®) and diphemanil methyl sulfate (Prantal®), which are anticholinergic, have been tried.

Such treatment has proved sometimes very helpful, sometimes of slight benefit, and often discouraging. Even though excess perspiration may be reduced, there are not infrequently unpleasant side-effects, such as a sensation oi heat, dryness of the mouth and throat, headache, and urinary retention. In the amputee, who often has an overheating problem in the first place, any further impairment of his cooling mechanism may not be tolerated. In some cases, however, an effort to control excessive sweating may be worth a try; certainly any drying effect that such drug therapy may exercise in the stump area will contribute to the hygienic state of the stump skin.

*Eccrine Sweat Retention.* In profuse sweating, the sweat is expelled from the eccrine glands onto the surface of the skin at intraductal pressures ranging as high as 250 mm. of mercury. If the outlet at the surface of the skin becomes blocked by masses of keratin, local inflammation, or other obstruction, this pressure may be sufficient to cause rupture of the duct (Fig. 3). If the rupture takes place near the surface at the level of the horny, or keratin layer, the sweat collects in this layer in a raindroplike configuration of little blisters. If the rupture is deeper in the skin, there may be local inflammation, characteristic of "prickly heat." Where the duct is ruptured still more deeply, symptoms are few or none, and the only surface sign consists of small, noninflammatory elevations, or "papules."

Sweat retention may involve most of the skin surface of the body and may be accompanied by pronounced generalized symptoms of fever, headache, and exhaustion, a condition usually confined to tropical climates. More commonly it affects only a localized part of the body. It has been reported in many different types of eczema and in a variety of healing inflammatory lesions. Preliminary investigations of eczematous eruptions of the stump suggest that sweat retention occurs in this area also. The heat and humidity which prevail over the stump skin during use of a prosthesis are factors which encourage the development of sweat-duct blockage and localized sweat retention.

### *The Apocrine Glands*

The apocrine glands, unlike the eccrine glands, develop from the follicular epithelium of the hair, as do the sebaceous glands. Apocrine glands are much larger than eccrine glands, and they are limited in their distribution to the underarm area, the breasts, the midline of the abdomen, and the anal and genital areas. Modified apocrine glands are also found in the external canal of the ear and in the vestibule of the nose.

The apocrine secretion is a turbid, whitish-to-yellowish fluid which dries like glue to form a light-colored plastic. The total number of apocrine glands is greater in women than in men, and axillary sweating starts earlier in adolescent girls than in adolescent boys.

The apocrine glands in the groin and axilla are occasionally the site of a chronic, extremely stubborn disease of the skin called "hidradenitis suppurativa." This disease is characterized by large, burrowing, painful cysts which are filled with a foul discharge. These periodically break down and drain, then heal with scarring, and the process may be repeated indefinitely. Frequently the condition is so severe that surgical extirpation, followed by skin-grafting, affords the only means of controlling it. Rarely, hidradenitis suppurativa is encountered in amputees. In such cases it can cause a really serious handicap, making the use of a prosthesis or crutches impossible.

Innervation of the apocrine glands is exclusively adrenergic, as compared with the cholinergic innervation of the eccrine glands. The apocrine system responds sluggishly or not at all to heat. However, it does respond promptly to emotional or painful stimuli. In the management of this aspect of the amputee's hygiene, therefore, it is important to bear in mind that pain or tenderness in the stump, or an emotional disturbance, may aggravate any existing skin disorders in the groin or underarm regions through stimulation of this specialized glandular system.

Unfortunately, the apocrine glands occur in the areas upon which the amputee must depend for support in the use of a crutch or an above-knee prosthesis. The apocrine glands can be a source of considerable grief, if, through poor hygiene, infection, or other cause, these areas are allowed to become unserviceable for weight-bearing.

*The Sebaceous Glands*

The sebaceous glands occur wherever there are hair follicles. In addition, there are scattered, free sebaceous glands which are independent of the follicles. Their secretion is an oily liquid composed of fatty acids, alcohols, hydrocarbons, and certain vitamin precursors. This material, called "sebum," becomes solid at about 30°C (86°F), the prevailing skin-surface temperature.

A unique feature of sebaceous-gland secretion is the capacity of the glands to secrete very rapidly onto a defatted skin surface, but at a rate which gradually declines until the new fat layer of the surface reaches a certain critical thickness. When this occurs, sebum production stops or falls to a minimum. If, however, the fat layer is removed, rapid secre-

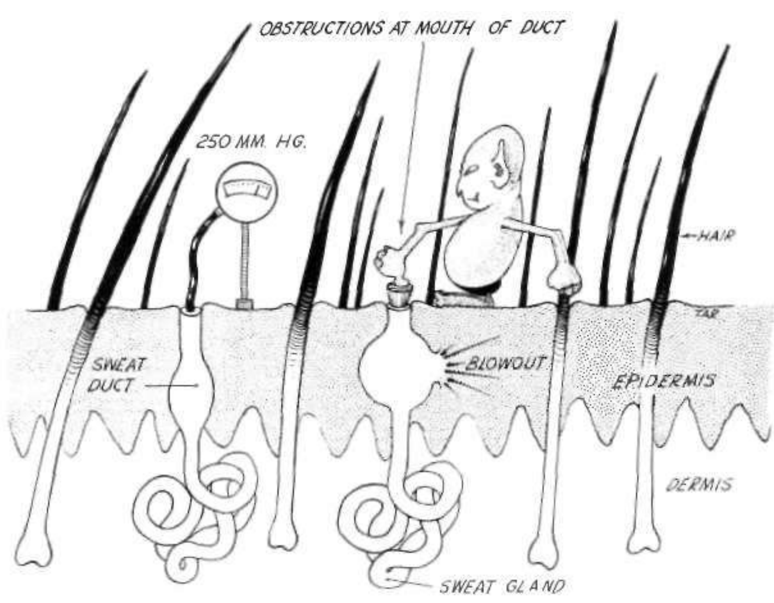



Fig. 3. Pressure in eccrine sweat glands. When an eccrine gland is actively secreting sweat onto the surface of the skin, the pressure in the sweat duct may rise to 250 mm. of mercury. If the opening of the gland becomes blocked, as symbolized by the gremlin, this pressure may be sufficient to rupture the gland duct and allow the sweat to escape into the skin.

tion starts again. The more viscous the sebum becomes, the earlier the sebum expulsion is stopped. As a result, more oil is secreted per unit time at a high environmental temperature than at a low temperature.

Presumably, the counterpressure of the oil film on the surface prevents further production by back-pressure in the gland. There is an interesting fact, however, which is not entirely explained by the back-pressure theory: if the duct of the gland is blocked by sebum only, no pathologic change takes place in the secretory cells of the sebaceous glands, but if the obstruction is caused by masses of keratin or other foreign matter, as in the case of comedones ("blackheads") and various types of follicular keratoses, degenerative changes in the gland set in relatively early.

This phenomenon of controlled oil production is one in which a normal physiologic process appears to work with the amputee rather than against him in the wearing of a prosthesis. Here, the accumulating lipid film under the socket will serve as its own shut-off valve for further secretion, without damage to the sebaceous glands in the stump skin.

## HEAT CONTROL AND THE HEALTHY SKIN

Healthy skin exercises a vital role in the thermoregulation of the body, a function in which the skin of the lower extremities normally has an important share. This surface control supplements the central heat-regulatory center in the hypothalamus of the brain. At basal conditions, the heat balance of the normal body is maintained by cutaneous vasomotor adjustment through an environmental temperature range of 25° to 31°C (77° to 88°F), the so-called "zone of vasomotor control." Above this range, at 31° to 32°C (88° to 90°F), when cutaneous blood flow has reached its maximum, sweating sets in—the "zone of evaporative regulation." Between 31° and 36°C (88° and 97°F) and at low humidity, evaporative heat loss easily maintains normal temperature. Below the zone of vasomotor control, the skin temperature falls, and body temperature is maintained chiefly by chills (the "zone of cooling"). If environmental temperature is maintained below a critical level of 31° to 32°C, there is generalized, but grossly invisible, periodic sweating known as "insensible sweating." Consequently, although the principal thermoregulation in this temperature range is vasomotor, there is still an assist from the sweat glands in cooling the skin surface.

The values cited are those reported for the normal. In the amputee, significant areas of cooling surface, along with the component sweat glands, have been subtracted from the total reserve of functional skin surface. In addition, the complex and important system of vascular shunts and arterioles in the amputated limb or limbs has also been lost from the total heat-regulatory mechanism. As a result, a number of characteristic and troublesome disturbances of temperature and heat control are associated with amputation.

Among these is the phenomenon of the poikilothermic stump, which has been studied by staff members of the University of California Medical School *(22)*. In this condition, the surface temperature over the distal part of the stump, and over a considerable portion of the stump proximally as well, tends to become stabilized at the temperature of the surrounding air, more or less independently of any vasomotor control. Thus it is seen that, in a lower-extremity amputation, not only is part of the original heat-control surface permanently lost but the remaining stump surface is no longer normally effective as part of the heat-control mechanism. Nevertheless, it is important to maintain the hygiene, or good health, of this remaining skin area in order to preserve whatever function it may still possess for heat regulating, and particularly for cooling.

## MECHANISMS of HEAT LOSS

Heat loss from the normal skin takes place by radiation, convection, conduction, and evaporation. All of these mechanisms are interfered with, if not entirely abolished, over the stump area when a tightly fitted socket is worn, Excessive local heating of the stump can result (Fig. 4), particularly during warm, humid weather, and a major hygienic problem can arise under such conditions.

Heat loss from the skin by radiation takes place in the form of infrared rays in the range of 5 to 20 m/u. Under normal conditions, radiation accounts for about 60 percent of total heat lost from the body. In the amputee, it

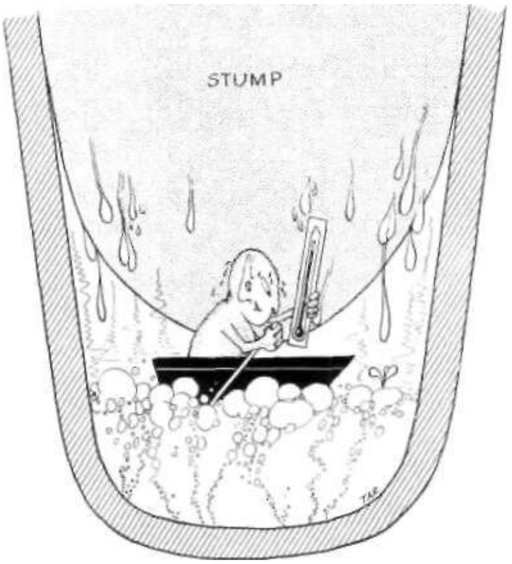



Fig. 4. Overheating of the stump. Since air cannot circulate inside a snugly fitted socket, the stump is usually bathed in sweat.

seems probable that loss of heat from the stump area by this mechanism is greatly restricted by the socket of the prosthesis. We do not at present, however, have any data to confirm this supposition.

Convection depends upon the transfer of energy by means of moving air and thus is negligible as a means of heat loss from the stump when a prosthesis is worn.

Conduction, the transfer of heat between two media in direct contact, is of great importance to the amputee. As the socket becomes warmed to skin temperature, it acts as an insulator against further dissemination of heat from the surface of the stump. It appears probable also that in the vicinity of principal loading, especially along the medial, anterior, and posterior segments of the socket rim, heat is generated by the friction resulting from shearing action between the skin and the socket rim. The insulating effect of the socket would, of course, tend to maintain any such local elevation of temperature. We are initiating a clinical study of this question, employing thermistors for the direct reading of skin temperatures while the prosthesis is being worn under various conditions of normal use.

Just how significant increased local heating of the skin may be in adversely affecting skin hygiene and metabolism over a long period of time we cannot say at present. It is known that an increase in environmental temperature elevates the oxygen and nutritional requirements of most tissues. At the same time, the blood supply to the skin of a lower-extremity stump, if changed at all by the active use of a prosthesis, is probably reduced. One might speculate here whether the predilection of these weight-bearing sites for the development of recurrent "pressure sores" may not be related to increased local heat plus diminished nutrition, as well as to mechanical damage and to maceration from sweat. Certainly this area of stump hygiene merits further investigation.

### REFLEX SWEATING

If, in the normal person, the environmental temperature is raised above a critical level between 31° and 32°C (88° and 90°F), there is a sudden, visible outbreak of sweating over the whole body. A similar response, termed "reflex sweating," may be observed when only a portion of the body surface is heated. Whenever there is excessive heating of the stump, the conditions favor reflex sweating, even though the environmental temperature of the rest of the body is below the critical level necessary for visible sweating. Certainly a valuable contribution, both to the comfort of the amputee and to the improvement of his stump hygiene, would be the development of new socket materials and designs which would provide for more rapid heat transfer by conduction and radiation to the outside air.

Loss of heat by evaporation from the stump is negligible in the case of the suction socket. Where the conventional socket is worn with a wool stump sock, however, the wicking action of the sock may well provide an avenue for evaporation and consequent cooling. A light stump sock for use with the suction socket may prove feasible. If so, the cooling effect, as well as the added support and protection afforded the stump skin, would be of benefit in maintaining a healthy stump.

According to Rothman *(15),* sweating which is elicited by exercise begins at a lower skin temperature than does sweating produced by external heat. Bazett (2) suggested that there may be, deeply situated near vascular plexuses, thermal receptors which are warmed by the working muscles. These receptors may in turn activate the sweat glands of the skin. Whatever the true explanation may be, the combination of excessive sweating (Fig. 5) and increased energy requirements for locomotion is all too familiar to the lower-extremity amputee.

Visible sweat secretion and heat loss can also occur independent of thermoregulatory needs. For example, sweating can be elicited with ease at air temperature below 31°C (88°F) by the ingestion of hot drinks, probably through a viscerocutaneous reflex. A variety of other nervous impulses unrelated to heat control may produce sweating. One of the most important of these is "emotional sweating," which may at times affect most of us to some degree. In dermatologic practice, we sometimes see patients in whom this condition has become so severe as to be almost incapacitating. Serious limitations affecting social contacts and employability result. The same disturbance of sweat mechanism may be experienced by amputees. Although the emotional factor may be important in some amputees who have a troublesome hyperidrosis, it is apparent from some of the known physiologic mechanisms for sweating that there may be other reasons for such an increase.

Fig. S. Excessive sweating. An amputee using an artificial leg may complain more of general bodily discomfort from heat and excessive sweating than would a normal individual undergoing similar exertion.

## STUMP HYGIENE AND GERMS

It has been a matter of frequent observation that the normal skin is not a sterile skin. Such a condition simply does not exist. Normal skin teems with immense numbers of unseen organisms, some harmless and some pathogenic, that is, capable, under the right combination of circumstances, of causing an infection of the skin. Normally, the harmful bacteria and fungi are held in check by a number of different forces. Most of the time we live in some measure of harmony with this enveloping horde. But when resistance to infection is lowered by local skin damage, the presence of some generalized disease, a metabolic disturbance such as diabetes, or any one of numerous other causes, then this harmonious balance is destroyed and the avenue of invasion is opened. Two different classes of bacteria exist on normal skin under average conditions—the resident bacteria, which remain fairly constant, and the transients, which may be almost anything (Fig. 6). In addition, a variety of fungi come and go, chiefly members of the yeasts and molds, although other types, such as those which cause ringworm of the feet and body, may be present.

Evans *et al.* *(11)* have studied the resident bacterial flora in 146 sample scrapings from the skin of 17 adults over an eight-month period. They found that the anaerobic bacteria (those which grow in the absence of free oxygen) outnumbered the aerobic bacteria (those which require free oxygen) by a ratio that ranged between 10:1 and 100:1. In most of the cases, one species of anaerobic bacteria predominated, the so-called "acne bacillus," *Propionibacterium acnes (Corynebacterium ac-*

*nes).* Of the aerobic bacteria, two species were observed regularly: *Micrococcus epidermidis* and *Staphylococcus albus {Micrococcus pyogenes),* the latter a skin pathogen The observation was made that, at least in cultures, some types of bacteria inhibited the growth of others. This finding might constitute one explanation for the overgrowth of certain bacteria, especially the acne bacillus, at the expense of the others. It was also found that the sebaceous glands were the major site of growth of bacteria on the skin and that exercise with sweating caused a transient minor increase in skin flora.

What effect might the wearing of an occlusive prosthesis be expected to have on common skin pathogens trapped under the socket? How might the normal defenses of the skin be affected by the conditions attendant upon the use of a prosthesis? To answer these questions, let us consider four common groups of organisms which are likely to cause skin infections in the region of the amputee's stump—the gram-negative organisms like *Escherichia coli,* the staphylococci, the beta hemolytic streptococci, and *Proteus,* some strains of which are secondary wound invaders.

We know that the normal skin surface has two important natural defenses against bacterial invasion—first, the ordinary drying action on the surface, facilitated, where the skin is uncovered, by the movement of air currents; second, the presence of unsaturated fatty acids (particularly oleic acid), which are components of the sebum, or oily secretion from skin oil glands.

Gram-negative organisms, that is, those organisms which do not retain the selective blue dye used in the Gram staining technique, are particularly sensitive to drying. This alone is effective in killing or inhibiting their growth. Unfortunately, the dry state never exists for any length of time over the stump skin during the use of a prosthesis.

Both the drying and the action of the fatty acids are slightly to moderately inhibitory against the staphylococcal organisms. In other words, neither factor offers sure protection

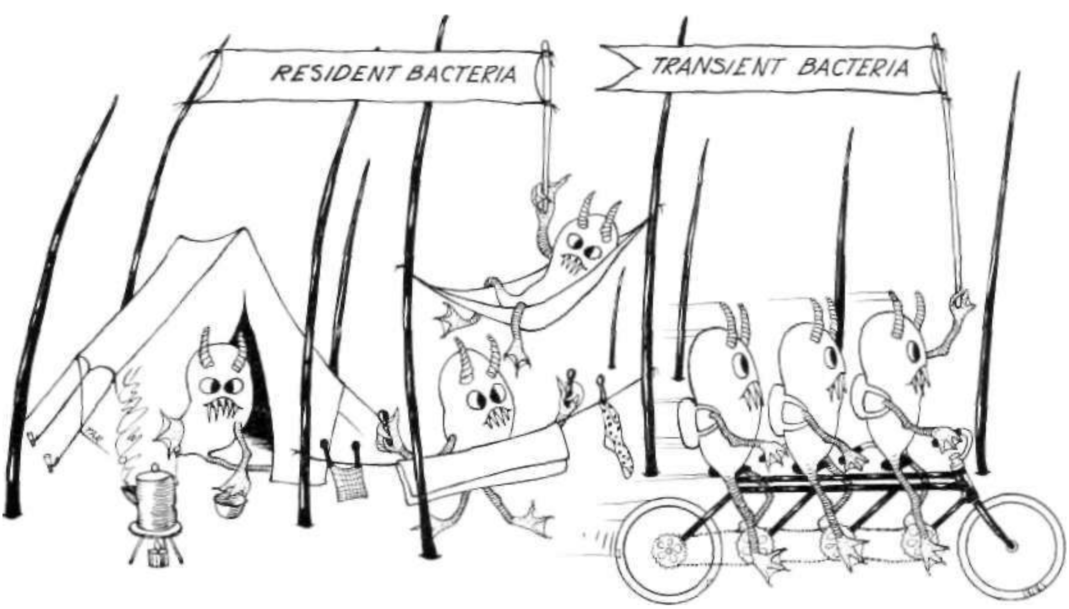



Fig. 6. Flora of the skin. Of the teeming numbers of microorganisms on the normal human skin, some are resident bacteria, which are found on the skin more or less constantly, while others are transient bacteria—only temporary visitors. Common among the residents are *Corynebacterium acnes,* the so-called "acne bacillus"; *Micrococcus epidermidis;* and *Micrococcus pyogenes,* a skin pathogen.

against invasion by this group of germs, but both have deterrent value in the normal skin. Again, the moist state which usually exists under the socket tends to encourage the growth of staphylococci.

Although the beta hemolytic streptococcus is unaffected by drying, it is destroyed by oleic acid. But streptococci will grow in serous exudate, such as may be seen in a weeping eczematoid dermatitis of the stump, because the albumin in the exuded serum neutralizes the oleic acid, the chief natural antagonist of the streptococci. This relation of exudative lesions of the skin to secondary infection underlines the importance of adequate hygienic care in routine management of minor abrasions and irritations of the stump area. Furthermore, it should be apparent that there are times when the continued use of a prosthesis on a stump which is the site of a dermatitis, especially where a serous discharge is present, will prevent healing and is almost certain to invite a secondary infection.

The *Proteus* strains—the fourth group of organisms mentioned—multiply rapidly in a moist environment. Any occlusive dressing or cover, such as the socket, which tends to increase local moisture on the skin will favor a heavy overgrowth of *Proteus.*

Thus we see that, in all four of the examples cited, the use of a prosthesis may be expected in some measure to interfere with the defensive mechanisms of normal skin in its resistance to disease. This interference is augmented by prolonged or strenuous use of the prosthesis and by the presence of any pre-existing lesions, however minor they may seem to the amputee.

## ELECTRICITY AND THE SKIN

The electrical behavior of the skin plays an important part in the preservation of good health. Normally, there is a negative electrical charge in the superficial layers of the skin. When an alkaline condition prevails, this electrical negativity is increased owing to adsorption of negatively charged hydroxyl ions. An acid condition of the skin, however, causes a discharge of this normal negativity, which is complete between pH 3 and pH 4. As the relative acidity of the skin increases, there is eventually a reversal of the charge, the skin surface becoming electrically positive. Furthermore, investigators have reported that scarring of the epidermis *(14)* and prolonged soaking in water or concentrated salt solutions *(13)* tend to cause a discharge of the normally negative charge of the skin. Both of these abnormal conditions may develop over the stump as the result of use of a prosthesis.

Just what effect socket wear has on the normal electrical behavior of the stump skin, or how significant this may be in maintaining a healthy condition in the stump area, we do not know at the present time. This is, however, another problem that should receive further investigation. We do know that the negativity of normal skin can be a factor in the defense of the body against pathogenic organisms, which are also negatively charged and which tend to be repelled from, or bound to, the surface of the skin according to variations in the electrical charge on the latter (Fig. 7). It is of interest, incidentally, to note here that in muscle the relationship of negative-positive electrical charges to normal and damaged tissue, as here described for the skin, is just reversed.

## STUMP HYGIENE AND LOCAL pH or THE SKIN

Blank *(3)* has confirmed earlier observations that the pH of healthy skin is always on the acid side, falling usually between 4.2 and 5.6. Furthermore, both eccrine sweat and apocrine

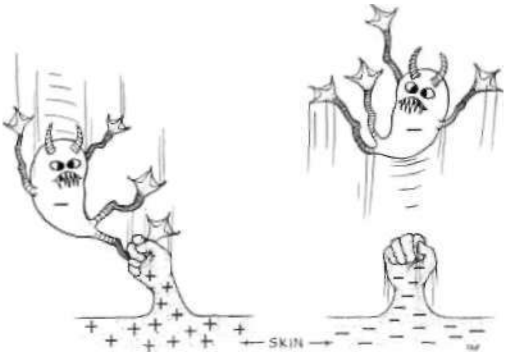



Fig. 7. Electrical charge on the skin as a defense against germ invasion. Germs, which are negatively charged, tend to be repelled from the normally negative surface of the skin but are attracted to the skin when this charge is reversed.

sweat are normally acid. These facts have given rise to the concept of the so-called "acid mantle" of the skin, which is cited by some investigators as one of the body's natural defenses against disease. Schmid *(17)* found a significant shift toward the alkaline side in the surface pH of the skin in cases of eczema and in seborrheic dermatitis, an inflammatory disorder involving especially the hairy and more oily regions of the skin. In general, an even greater shift toward the alkaline side takes place in these inflammatory diseases if the intact skin is broken and neutral in charge or if alkaline extracellular fluid diffuses through, as in any acute, weeping dermatitis of the stump. With healing, the original acid pH returns.

### BUFFERING ACTION OF NORMAL SKIN

Another important property of the skin is its buffering action. If the skin surface is exposed to dilute acids or alkalies, there is normally a corresponding shift of the pH locally; but this is temporary, and the former acid pH is rapidly restored. This behavior represents the neutralizing capacity of the skin. Probably the most important agents in this neutralizing property are the sweat constituents, especially the lactic acid-lactate system and the amphoteric amino acids. Any local damage to the sweat mechanism, such as might be caused by socket irritation, could conceivably impair this important function of the skin in the involved areas. Burckhardt *{7,8)* and others have established that there is a definite correlation between the acid and alkali neutralizing capacity of the skin and its tolerance for acids and alkalies.

Pursuing a discussion of acid-base balance brings to mind several unanswered questions with regard to the amputee's problem of stump hygiene. We would like to know, for example, what happens to the normally acid pH of stump skin during the daily wearing of an airtight socket. Does stump skin possess the same pH and buffering properties as the skin of an intact limb? What effect do different socket materials have on the pH of stump skin? Does an interior finish which gives an alkaline reaction necessarily cause more damage to the skin than does one with an acid reaction? These are questions which should receive further investigation in the light of their vital relationship to stump hygiene.

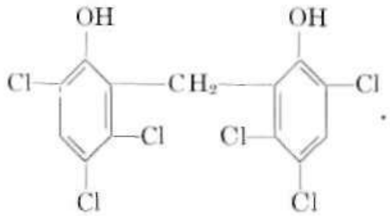
It might seem from the foregoing that the cutaneous surface which gives an acid reaction denotes a healthy skin, resistant to invasion and disease, while an alkaline-reacting skin surface denotes the presence of some disease state. Unfortunately it is not quite so simple. Some organisms grow readily on an acid medium. Pathogenic fungi, for example, flourish on certain media at pH 4.9. Nonetheless, in general, it is desirable to maintain the surface of the skin at least slightly on the acid side.

Washing, even with plain water, causes moderate hydration of the horny layer, with a drop, according to Szakall *(21),* from pH 6.3 to pH 5.3 in 30 minutes. This information may also have some application to lower-extremity prosthetics, since the stump skin becomes soaked with sweat in most cases shortly after the prosthesis is put on. Furthermore, a single washing with soap removes about 50 percent of the surface lipid film, thereby facilitating the outward diffusion of carbon dioxide, the acid reaction of which helps to neutralize an alkaline state on the surface of the skin.

### SURFACE pll AND DEGERMING OF THE SKIN

Control of surface pH is also important in degerming the skin. Blank, Coolidge, and others *(4,5,6),* in an extensive study of the surgical scrub, have investigated many different germicidal agents and techniques of cleansing. Among the agents studied were the quaternary ammonium compounds, like Ceepryn® and Zephiran,® which are widely used in surgical cleansing of the skin. While these compounds do exert a bacteriostatic or bacteriocidal effect, Blank *et al. (6)* found that they also have the property of binding the bacteria to the skin. It was demonstrated that, at a pH a little higher than the isoelectric point of keratin, the quaternary ammonium compounds change the normally negative charge on the surface of the skin to positive. Since the bacteria are negatively charged, they are attracted to the skin. If the pH is then increased considerably, for example by rinsing with an alkaline soap, the charge on the skin will revert to negative and the bacteria will be released from the skin, as has been confirmed experimentally by analysis and culture of the rinse water.

Another germicidal agent commonly used in disinfecting the skin is G-ll,® or hexachlorophene. Chemically it is 2,2'-methylenebis (3,4,6-trichlorophenol):



This compound has the double advantage of accumulating on the skin when used daily and of not being inactivated, as most germicides are, when combined with a detergent. If used only at infrequent intervals, G-ll is no more effective as a disinfectant than any nonmedicated soap. If used regularly, however, within five to seven days there will develop in the skin a concentration sufficient to cause a definite reduction in the bacterial flora. One contraindication to the use of this agent is the presence of a serous ooze, such as we see not infrequently on the stump in various types of eczematous skin conditions. Seastone *(19)* has reported that as little as 1.0 percent of sterile serum will reduce the bacteriostatic effect of this agent.

Hexachlorophene is available commercially in combination with various soaps and liquid detergents, in strengths varying from 0.75 to 3.0 percent. These include such brand names as Dial® soap, Gammaphen® soap, pHisoHex,® and Septisol.® Another useful preparation of G-ll is an alcoholic solution containing 0.1 percent of G-ll, with 0.5 percent of cetyl alcohol added as an emollient. This solution may be used as a two-minute rinse following soap-and-water cleansing of the stump.

A useful cleansing agent for stump skin has been found to be pHisoHex, especially where superficial infection is a problem. It consists of an emulsifying agent known as pHisoderm,® to which 3 percent of G-ll has been added. Chemically, pHisoderm is sodium octylphenoxyethoxyethyl ether sulfonate, plus lanolin cholesterols, lactic acid, and petrolatum. Its pH is 5.5, approximately that of normal skin. It lowers the surface tension of water and is an active emulsifier.

There are many other agents for degerming the skin, many of which are too irritating for the type of regular use necessary to routine stump care. One of the more readily available of these is alcohol, which remains a useful bacteriocidal preparation. Isopropyl alcohol, for example, is germicidal up to 50-percent dilution. Too-frequent use of such solvents, however, will dry the skin excessively and may do more harm than good. Furthermore, any marked depression of bacterial flora over the stump skin cannot be maintained for long during use of the prosthesis.

## SELECTIVE ABSORPTION AS A PROTECTIVE BARRIER

The healthy cutaneous envelope of the body is constantly active as a physicochemical barrier against the outside world, retaining some substances and passing others through (Fig. 8). As early as 1904, Schwenkenbecher *(18)* showed that the intact skin is permeable to fat-soluble substances and to certain gases but is practically impermeable to water and most electrolytes. Most substances which are soluble in both water and lipids penetrate the skin and pass into the general circulation at rates comparable even to gastrointestinal or subcutaneous absorption. Phenolic compounds, lipid-soluble vitamins, and hormones penetrate rapidly. This property of the skin conceivably could be of serious import in the indiscriminate use of socket materials or finishes capable of liberating absorbable toxic fractions which could be taken up by the stump skin.

In rare instances, individuals have demonstrated a peculiar sensitivity, known as an "idiosyncrasy," on first exposure to certain drugs and chemicals applied to the skin. Alexander *(1)* described a case of iododerma, a form of iodine reaction, resulting in the death of a 37-year-old woman following routine preoperative cleansing of the surface of the skin over the abdomen with iodine. This is not

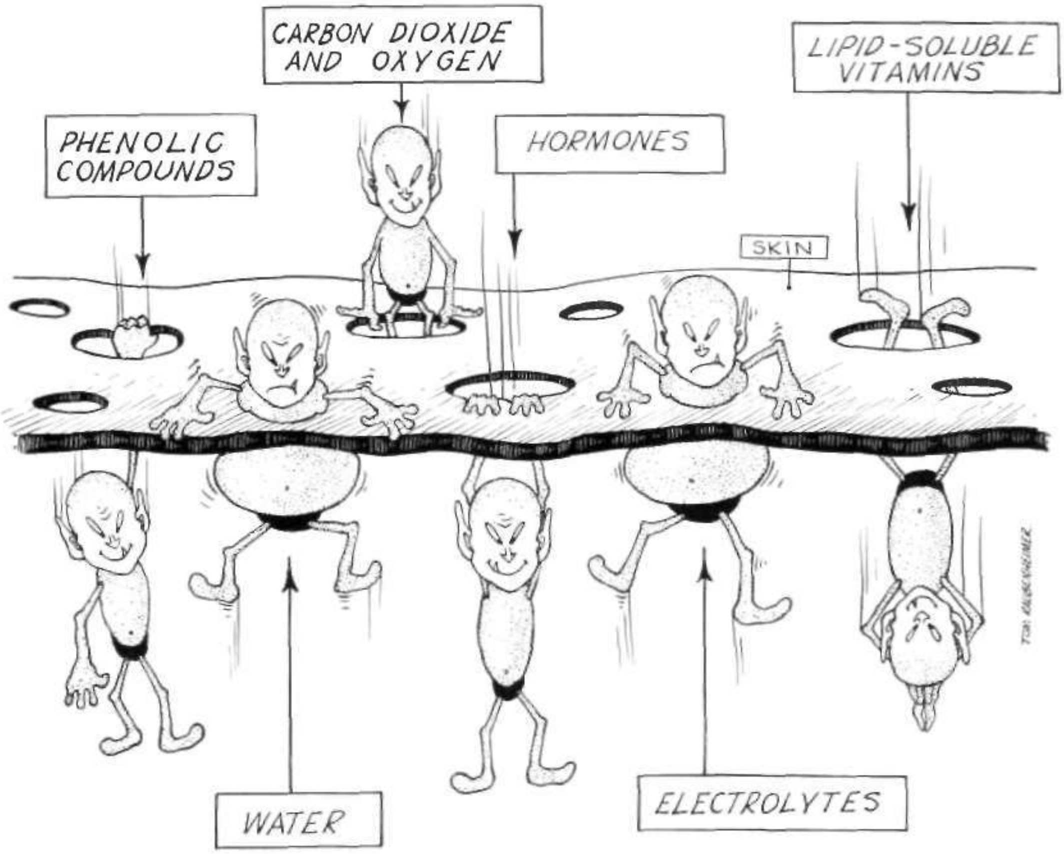



Fig. 8. The skin as a protective physicochemical barrier. The skin conserves in the body some substances like water and electrolytes by selectively barring their outward passage. Other substances, for example the gases carbon dioxide and oxygen, are passed freely through the skin. Lipid-soluble vitamins and hormones likewise readily penetrate the skin barrier. Unfortunately, certain materials which are potentially toxic, such as the phenolic compounds, may also be freely absorbed by the skin. Care should therefore be taken to avoid prolonged intimate contact with such materials.

intended to suggest that any similar hazard exists in the use of present-day, conventional socket materials. It does, however, emphasize the fact that the skin may be, in certain rare cases, an open portal to the systemic circulation.

Transfer of gases across the skin barrier may take place with ease in either direction. The biological significance of the movement of oxygen and carbon dioxide through the skin, which was once thought negligible, is given more importance now. Shaw and others *(20)* found that oxygen was given off through the skin when the oxygen content of the ambient air was reduced to about 2 percent and that it was absorbed more rapidly when the skin was surrounded by a gaseous mixture containing about 37 percent of oxygen than when surrounded by air. According to Chambers and Goldschmidt *(9),* if the total skin surface is surrounded by nitrogen gas instead of air, there may be a compensatory, increased uptake of oxygen by the lungs.

Hediger *(12)* reported that, from a water chamber containing the dissolved gas, carbon dioxide passed into the skin as long as the water contained more than 4 percent of carbon dioxide. When the concentration dropped below 4 percent, carbon dioxide diffused outward through the skin, as it does constantly under physiological conditions. Measurements cited by Rothman and Schaaf *(16)* showed that over a 24-hour period 7 to 9 grams of carbon dioxide escaped from the total skin surface, less that of the head, of an adult male. The amount suddenly increased when the temperature was raised to the critical temperature of visible sweat secretion.

Cleansing of the skin with organic solvents such as ether, benzene, and, to a lesser degree, alcohol, enhances percutaneous absorption, that is, absorption across the skin barrier. Since such solvents are used frequently in the cleansing of the stump, as well as of the interior of the prosthetic socket, this effect upon the skin's absorption should be borne in mind. Moisture, almost constantly present in the wearing of a prosthesis, also promotes transepidermal absorption by an unexplained mechanism.

## SUMMARY

Through the use of improved prostheses, many amputees have been able to return to relatively normal physical activity and to take again their rightful place in business and social life. It must be remembered, however, that the use of a prosthesis places upon the leg amputee new and heavy demands, including not only muscular and emotional readjustments but also the infliction of unaccustomed wear and tear upon his stump skin. Daily, for the rest of the amputee's life, his stump will be subjected to an abnormal environment that combines heat, moisture, and darkness with chemical and mechanical irritation. It becomes imperative then, in restoring the amputee to full activity, to make certain that he understands the importance of systematic skin care. An adequate appreciation of the necessary requirements for good stump hygiene must be based on a knowledge of the functions and limitations of normal skin.

The skin provides for the other tissues a highly effective, tough and elastic outer covering, which has a great capacity for strengthening itself at points of stress and for repairing itself after injury. But this capacity of the skin for mechanical protection, the limits of which are of special interest in prosthetics design, is only one of its many important functions. The skin possesses, in addition, a variety of anatomical structures, including the eccrine, apocrine, and sebaceous glands, the normal function of which is necessary for the preservation of good skin hygiene. The eccrine glands are indispensable in the heat control of the body. All of the glands produce secretions, some of which are exceptionally copious. This normal function poses an important sanitary problem for the amputee and makes routine cleansing of both the skin and the prosthesis essential.

The natural defenses of the skin against germs depend upon good hygiene. Conditions inside the socket tend to impair the resistance of the skin to infection, but through adequate cleansing, frequent airing, and intelligent care of early lesions, serious infection may be avoided.

Knowledge is increasing concerning the electrical and chemical buffering properties of the skin and their role in the maintenance of skin health. There is usually a negative charge in the superficial layers of normal skin. It is, however, discharged by injury or by prolonged soaking in water or salt solution. Similarly, normal skin is slightly acid, but in the presence of inflammation of the skin a shift to the alkaline side usually occurs. The sweat constituents contribute largely to the capacity of the skin to neutralize or buffer dilute acids and alkalies to which it is exposed. Whether or not these properties are retained intact by the stump skin of amputees and, if so, how they are affected by the conditions of use of a prosthesis are important areas for further research.

Although the skin serves as a protective barrier, it is readily penetrated by certain substances. For this reason the stump should be protected from contact with materials potentially toxic. Similarly, the stump skin may be subject to a variety of local injuries—mechanical, chemical, or allergic in origin. Again the importance of early and close attention to minor lesions and to good preventive hygiene must be emphasized.

There have been two chief aims in this discussion of basic principles. The first was to impart an awareness of the complex nature of the problem of stump hygiene and the second to emphasize that good stump hygiene, far from being an academic matter, is one of the utmost importance to the amputee. Like the proverbial dispatch rider whose horse was crippled for want of a horseshoe nail, the amputee may suffer discomfort and serious disability because of neglect of a seemingly insignificant lesion or failure to follow a simple cleansing routine.

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