1947

Physiology and treatment of severe burns : with special reference to burn shock

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THE PHYSIOLOGY AND TREATMENT OF SEVERE BURNS, with SPECIAL REFERENCE TO BURN SHOCK.

by

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SENIOR THESIS PRESENTED TO THE COLLEGE OF MEDICINE, UNIVERSITY OF NEBRASKA, OMAHA.

1947.

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I.
INTRODUCTION.

The problem of burns, physiology of burns, treatments of burns, and complications of burns has recently assumed a prominent position in the literature of the medical profession. Various articles have appeared in the publications extolling the advantages of this treatment, the disadvantages of that treatment, or the physiological basis for some other form of treatment. However, relatively few investigators have attempted to correlate the many physiological changes which accompany any severe burn with the therapy used in treatment of the lesion. In this paper I shall review the recent literature with an aim toward correlating the various pathological processes in the body with the more recent methods of treatment of burns. The discussion will be limited to that picture presented by severe or third degree burns, and no attempt will be made to discuss any of the complicated surgical procedures used in skin-grafting or repair of orthopedic complications resulting from burns.

II.
DEFINITION OF TERMS.

This discussion will be limited to the pathological picture presented by severe burns. The writer recognizes the fact that many burns may be severe injuries and yet not be third degree burns, but the majority of these will have more or less involvement of the skin surfaces to the degree that they may be classified as containing areas of third degree burning. For purposes of definition, a severe burn will be considered to be that lesion caused by external thermal elements which involves more than twenty per cent of the body surface area of the victim or which causes necrosis of the skin and escape of fluid from the lesion.

III.
THE INITIAL LESION.

Picture a small child pulling a pan of boiling water from a stove, a child accidentally igniting clothing soaked with gasoline found in an old tin can, an electrician unwittingly becoming a part of a "hot" circuit, or a fireman being injured by falling, flaming timbers. Any of these may be the cause of the initial lesion referred to as a burn. All present the same basic physiological alterations which must be considered in the course of successful therapy.

The appearance of a severe burn soon after its infliction may vary from being reddened and blistered to actual charring of the skin, the subcutaneous tissues, and even the muscles of the individual. There is no definite lesion of which it may be said that this and this only is a severe burn. However, a thermal injury in which there are blisters and oozing of a clear watery exudate from the area, or a lesion covering twenty percent or more of the body's surface, may be considered to be a severe burn. (23,34,37,50,54,58)

The microscopic picture in any severe burn is that of actual destruction of the cells of the skin in the area which has been subjected to the greatest injury. Around the periphery of the burn are found varying degrees of cellular damage, becoming less marked farthest away from the burned area. "A burn is a lesion due to heat in which

living cells are killed and neighboring cells injured in every degree." (Drinker, 1944) (34, 37.)

Capillaries and lymphatics at the site of the lesion are dilated and damaged to the degree that plasma and sometimes whole blood flows freely from the wound. (34, 50, 58.)

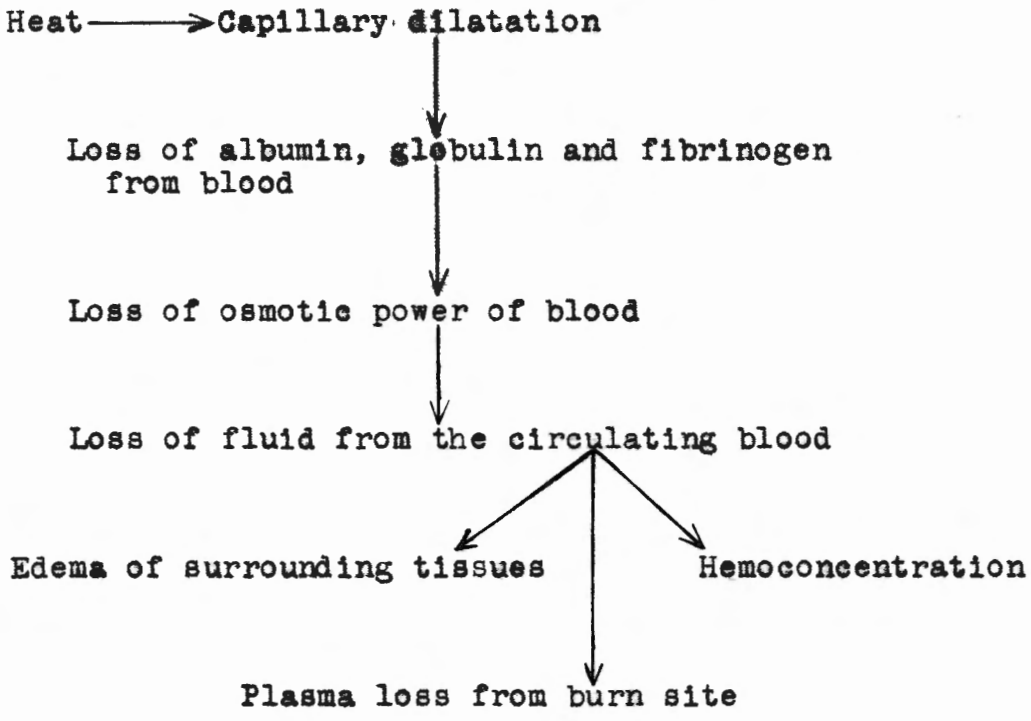
Elman and Lischer (1944) showed that there were two types of necrosis of the skin and subcutaneous tissues in severe burns and that either one or both may be present in a third degree burn. Because of their findings they reasoned that the type of necrosis present in a burn has much to do with the development of systemic manifestations. An area of dry necrosis contains skin which is hard and dry, but shows no other alteration in the normal appearance of the epithelium. The fibers of the dermis are swollen, but there is no other edema or inflammation. Such an area is not prone to infection. Contrasted to this is the easily infected area of dry necrosis from which the epithelium has disappeared, there is edema, and all the microscopic signs of inflammation are present. This type of necrosis is said to be present in most cases in which systemic disturbances occur following severe burns. (37.)

IV.
BURN SHOCK.

The most important problem facing the physician in the immediate care of a severe burn is the prevention and treatment of burn shock. This condition is either present or is an iminent danger in all severe burns, and cannot be separated from the general picture shown by these lesions. It is the most serious early complication of burns and must be treated immediately if the life of the patient is to be saved. (5)

The cause or causes of shock in severe burns has been debated for quite some time, but two factors which are present in all burns may be regarded as primary causes. These are (1) the pain resulting from thermal stimulation and injury to peripheral nerve endings and (2) the immense loss of fluid from the site of injury. Blalock (1931) found that the loss of fluids (roughly 3.3% of the body weight) in burns on experimental animals was enough to cause profound shock and even death. Elman and Lischer (1943) produced fatal shock in unanesthetized dogs by controlled loss of blood. They withdrew 10 cc of blood per kilogram of body weight every hour from each dog until the dog died, and found that the mean survival time in these animals in this experiment was 3.6 hours. The cause for the loss of fluid at the burn site may be attributed directly to capillary damage. The mechanism of this fluid loss is clearly

stated by Sturgis (1945) whose observations have been used in the preparation of the following diagram: (18, 36, 112)



Cope and Moore (1944) state that "....in a pathologic state the capillary membrane may become as permeable to colloids as it was formerly to ions." Thus, it is easily seen that the plasma proteins may be lost in great quantities through these damaged vessels. The rate of the fluid loss from the lesion has also been the subject of interesting and quite important observations. Weiner and his associates (1936) have observed cases in which the protein loss was so great that the serum protein level had dropped to as low as 4 grams % after the burn.

Rossiter (1943) states that 50% of the fluid loss occurs within 30 minutes after burns in experimental animals, and Harkins (1945) stated that the fluid loss occurred largely in the first eighteen hours postburn and was practically nonexistent at the end of forty-eight hours. McIver (1933) found that blister fluid from burns closely resembled plasma in composition, and this observation has since been confirmed by numerous investigators. The loss of plasma, according to Sturgis (1945), may be as great as 50% of the plasma volume. (104, 60, 81, 118, 27)

The fate of the fluid lost from the circulating blood is determined to some degree by the severity of the damage to the epitheal surface. In a second degree burn the loss of fluid is from the surface of the burn, but in a third degree burn the fluid is lost both from the surface and into the surrounding tissues (Harkins, 1945). Allen and Koch (1942) stress the importance of the occurence of the "White Hemorrhage" in severe burns, and state that this is a leakage of plasma into the tissues around the lesion. This is the cause of the commonly seen edema in severe burns. The amount of fluid lost by this route may be enormous and still cause no appreciable drop in arterial blood pressure. However, too extensive loss of fluid will eventually cause a sudden drop in blood pressure and the appearance of all the signs of shock (Harkins, 1945). (60, 5, 69, 61)

Accompanying the loss of plasma from the circulating blood is a resultant hemoconcentration. The increased viscosity of the blood then has a direct effect on cardiac efficiency, causing an increased burden on the heart. Seligman and his associates (1946) have found that the cardiac output can be returned to normal by massive dilution of the circulating blood (reducing hemotocrit levels to 10 or 20%), but that the experimental animal will not recover from the shock unless the blood volume is also restored. They further state "..if an abnormally high viscosity exists in shock and is not treated effectively, the restoration and maintainance of normal blood volume becomes all the more urgent."(107)

A conclusion easily drawn in the study of burn shock is that the fluid loss involves more than just loss of plasma. Since the capillaries have been injured to the degree that even colloids may escape, the loss of electrolytic substances would be very great. Fox and Keston (1945) used a radioactive sodium isotope in their studies of the mechanism of burn shock in experimental animals. They concluded that injury to the tissues causes sodium to leave the extracellular fluid space and to become intracellularly contained. The increased intracellular sodium causes fluid to be drawn from the extracellular fluid space to the intracellular space in order to main-

tain an osmotic equilibrium, and produced shock because of a decreased plasma volume. The sodium content of the injured skin and muscle was measured and found to be greatly increased, an increase which exceeded the tissue gain in fluid (edema) and indicates that there is sodium accumulation in the intracellular space. They treated the shock in these animals with isotonic solutions of sodium chloride in distilled water in quantities of 8,000--15,000 cc. during the first 48 hour period postburn and were successful in relieving all evidences of shock in many instances. Hechter, Bergman and Prinymetal (1945) compared serum, sodium chloride and glucose solutions as to their relative effectiveness in relieving scald shock. They concluded that the therapeutic value of an isotonic fluid in the treatment of burn shock is due to the sodium ion content of the fluid. They also used an isotonic solution of sodium succinate to rule out the possibility that the chloride ion may be the effective principle in isotonic fluids, since the use of sodium chloride and serum had shown nearly equal effects in equivalent quantities, and found that the sodium succinate solution was just as effective as a sodium chloride solution in the treatment of this type of shock. (48, 49, 62)

The question as to the possible role of adrenal damage in the production of burn shock has been debated upon by various observers in recent years. Nearly every pathologist who has performed a post-mortem examination

on a patient who has died of burn shock has noted adrenal damage to a greater or lesser degree. Rose (1936) advocated an immersion of the patient in cold water as an initial treatment for burns. He noted that there was almost immediate relief from pain and that the incidence of shock seemed to be decreased. The mechanism of action of the treatment was thought to be a prevention of capillary dilatation which was accomplished by the application of cold water. The possibility that this observation is an indication of the physiologic property of cold has not been proven. Rhoads, Wolff and Lee (1941) showed that they could apparently reduce capillary permeability for plasma proteins after burns by giving injections of adrenocortical extract. They could not show that this extract was of any value in restoring the circulating plasma volume, unless adequate plasma was added by transfusion to the general circulation at the same time as the extract was given. However, they noted that the amount of plasma necessary for restoration of the circulation plasma volume to normal seemed to be reduced if given simultaneously with adrenocortical extract. Since these initial observations, however, the afore-mentioned observers have been unable to find any response to the administration of adrenocortical extract in burn shock. Douglas (1944) speculated as to the necessity of the use of substitution therapy in case of adrenal damage in burns, and it was

her opinion that it may be necessary to use extracts of the adrenals as a life-saving measure. She states that soon after a severe burn there is a marked hyperactivity of the adrenal medulla, causing a great release of epinephrine into the circulating blood, but after 24 hours postburn there are marked degenerative changes in the entire gland. Thus, if we allow ourselves to speculate, the body may be robbed of the epinephrine necessary for maintainence of normal capillary tone and a state of shock may become virtually irreversible. However, Cope and Moore (1944), Glenn and his associates (1943), and numerous other observers have found that there is no increase in capillary permeability in normal regions of the body distant from the injured area. Bergman and his associates (1945) used a standardized method of scalding rats and mice and then tested various substances for anti-shock activity. The adrenocortical hormone, besides several other substances, was found to have little or no effect on the shock. (10, 27, 33, 52, 97, 39)

Studies have been conducted recently by Hechter and his associates on the possibility of the existence of a renal factor in burn shock. However, their experiments to date reveal no relationship of the kidney to this condition. (63)

V.
THE TREATMENT OF BURN SHOCK.

"A large burn .... is a suddenly opened reservoir into which the patient loses blood intravascularly. But, in addition, the walls of the reservoir are leaky, so that the amount of fluid entering the affected region is more than that returning from it to re-enter the general circulation. Intravenous infusion of plasma is the essential resource in such a state of affairs...." (51)
Glenn, Gilbert & Drinker, 1943)

The above quotation very aptly sets forth the essential principles for the present-day treatment of burn shock. Not until 1936 was the necessity for the use of plasma realized. At that time Weiner and his associates noticed that there is a marked degree of hemoconcentration and a decrease in serum protein to as low a level as four grams percent in patients suffering from burn shock. They concluded that the reserves of protein within the body were not sufficient to overcome the rapid loss of serum protein and that the best way to overcome this deficit in serum protein was to give transfusions of plasma and whole blood. They also condemned the administration of large amounts of glucose, water or electrolyte solution as being ineffective in raising the serum protein levels and as being a possible factor in the production of a generalized edema in the face of a low serum protein. Prior to these observations, shock in severe burns had been treated by various methods, some of which are worthy of mention: (118)

1. Immersion of the patient in a continuous warm water bath. -- This therapy was first used by Passavant in 1858, and was advocated for the relief of pain and to prevent absorption of toxic products from the burned area. (91)

2. Massive injections of salt solutions. -- LeJariel advocated this treatment in 1906. The salt solutions were either normal saline or Hayem's solution and were to be injected subcutaneously. He believed that intravenous injections were dangerous in burn shock because he feared that the salt solutions might damage blood which had already been traumatized by the thermal injury. This was probably the first effort toward fluid and electrolyte restoration in these injuries. (70)

3. Subpectoral salt injection, rectal shock enemata and large doses of morphine.--This was recommended by Risley, in 1920, for the prevention and treatment of burn shock. He also advocated immersion of the patient in a continuous hot (90°-100°F.) saline or boric acid solution bath if there was not rapid recovery from shock. The room during this time was kept superheated.--It is interesting to note that Drinker (1944) said that "External heat has but one purpose: To raise the body temperature to normal. Anything more than this is unfavorable in the treatment of shock, and for the collapse following severe burns even greater care must be exercised.."

Risley also recommends stripping the patient of all clothing and leaving him in the nude state in a room in which the temperature had been raised to 110°F. (99,34,113)

4. Pressure dressings. -- Blair (1924) advocated the use of pressure dressings in burns, and noted that the incidence of shock was decreased in those patients who were treated in this manner shortly after the injury was received. He attributed this to a control of fluid loss from the burned area. (16)

5. Cold water baths. -- Rose (1936) suggestedthe use of cold water immersion as a means of lessening the incidence of burn shock. The mechanism of action was said to be a prevention of capillary dilatation by the response of the capillary wall to the cold environment.(103)

Since the studies of Blalock (1931) indicated that enough fluid may be lost through the burn site to cause shock and even death, it is obvious that the ultimate objective in the prevention and treatment of burn shock must be to maintain or restore the circulating plasma volume to as nearly the normal level as possible. In order to achieve this end there must be a method or means of determining the amount of fluid which is necessary in any given case. Harkins (1935) emphasized the fact that the determination of arterial blood pressure is of little value in proving the exact circulatory status of the patient. There may be immense loss of fluid from the blood

vessels into the tissues without affecting the arterial blood pressure, and then the blood pressure suddenly falls. Because of this he recommended the use of one of several formulae for computing the amount of plasma necessary in any given instance. His own method is to determine the hematocrit of the patient and then give 100cc. of plasma for every point of hemoconcentration above the normal of 45%, provided the serum protein level was 6 grams % or more. In cases of decreased serum protein levels, he adds 25% of computed amount of necessary plasma for every gram of protein level below 6 grams. Another method of computing plasma need is to determine the amount of burned body surface area, according to Berkow's formula, and then to give 500cc. of plasma for every 10% of the body surface involved in the burn. The rate of administration of plasma, according to Harkins, should be: one-half of the required amount during the first six hours after treatment has been instituted, one-fourth during the next six hours, and remaining one-fourth before eighteen hours after the initial infusion. This allows for rapid administration of plasma, but the rate is not so great as to impair cardiac function. Glenn and his associates (1943) stress the need of giving the plasma fairly slowly:

> "...no good can be done if the plasma is given so rapidly that for a time the pressure is raised above a reasonable normal level for a prone quiescent patient. Invariably, the injured and inflamed area will receive an undue share of the fluid

> which is given....leakage of plasma will be directly proportional to the flow and pressure of the blood, and....one can count upon losing plasma rapidly if the infusion is intemperately hasty or unduly large in quantity."
> (11, 18, 55, 51)

What is gained by the use of plasma in the treatment of burn shock? Undoubtedly the most important reason for using any sort of fluid replacement therapy is the presence of a state of shock,which, if left untreated, could spell the death of the patient. The arterial blood pressure is extremely low and there is a greatly increased viscosity of the blood -- hemoconcentration. The heart is forced to work much harder than ever before to maintain even the minimal amount of circulation of blood necessary to sustain life. There is a constant drain on the body's fluids in the form of a damaged vancular bed at the site of the thermal injury. Along with the fluid loss there is a loss of essential electrolytic materials, most important ofwhich is the loss of the sodium ion. Thus, the question at this point is that of determining if plasma given to the severely burned patient can adequately correct this gross imbalance in the structure of the body. The report of McIver (1933) as to the composition of fluid escaping from a burned surface has been cited earlier in this paper. Cope (1944) calls attention to the fact that albumin is lost in greater quantities than globulin, probably because the albumin molecule is smaller. This causes an

upset in the albumin-globulin ratio of the body plasma, and, since the albumin molecule is said to exert greater osmotic pressure, a great drop in the osmotic pressure of the plasma. The decreased osmotic pressure causes loss of a fluid from the plasma into the extracellular space, particularly at and around the site of the burn where there is great capillary injury. The loss of fluid from the blood causes a state of hemoconcentration. The hemoconcentration and loss of fluid might be corrected by the use of intravenous injections of electrolytic solutions, but it is impossible to correct the protein loss rapidly unless there is replacement of the protein in its complete and usable form. Such an end is accomplished by using plasma or blood transfusions. The increased osmotic pressure brought about by administration of plasma slows the loss of body fluids containing electrolytes, and while the mineral losses are not completely corrected they are at least combatted. "Blood plasma is the best treatment known at this time for the treatment of burn shock. Since it is essentially plasma which is lost in burns rather than whole blood, the use of plasma would seem logical." (26, 61, 76, 78, 104, 107, 112, 117, 118)

Since the introduction of plasma as the treatment for burn shock, several investigators have used other fluids and solutions for the treatment of this type of shock in an effort to find an even better means of correcting the condition. Evans and Rafal (1945) treated

patients with an intravenous gelatin solution and found that this solution seemed to control shock as well as plasma. However, they noted that the gelatin had little effect of raising serum pretein levels. Evans and Bigger (1945) in a continuation of the above study, used whole blood transfusions, even in the presence of moderate or severe hemoconcentration. They found that the secondary anemia which is commonly seen following severe burns did not appear, and that the state of shock was effectively relieved. They also found that the plasma protein levels seemed to remain more stable in their series of patients treated with whole blood than in other patients treated with plasma. Elman and Lischer (1943) produced a state of fatal surgical shock by bleeding unanesthetized dogs at the rate of 10cc. per kilogram body weight every hour. They then replaced the blood with certain solutions in an effort to show the relative effectiveness of these solutions in the treatment of shock. Their results are shown below:

1. No fluid replacement.-----Death in 3.6 hours.
2. Glucose in normal saline.-----Death in 3.6 hours.
3. Pure amino-acids.-----Death in 4.2 hours.
4. Hydrolyzed proteins.-----Death in 5.15 hours.
5. Citrated plasma.-----Death in 4.5 hours.
6. Citrated serum.-----Death in 4.6 hours.
7. Heparinized plasma.-----Death in 4.6 hours.

They also noted that the fall in blood pressure was more pronounced in those animals treated with citrated plasma or serum than in those which received heparinized plasma. This infers that the heparinized plasma is far superior to citrated plasma (in use at the present time) for the treatment of shock due to repeated hemorrhage. Moyer and his associates (1944) inflicted severe scalding burns on anesthetized dogs and found that a combination of defibrinated blood and sodium chloride - sodium bicarbonate by mouth was the most satisfactory method of treating the resultant shock. All of the animals were given 10% of their individual body weight of the various fluids used in their experiments. (85, 36, 41, 43)

After Moyer, et al.(85)

Solutions used	Results
1. Defibrinated blood, intravenously, plus sodium chloride-sodium bicarbonate orally.	1. Prevented shock. No complications which were incompatible with life.
2. Normal saline - sodium bicarbonate, intravenously.	2,3,4,5. All prolonged life over that of a control animal given normal saline. Shock was prevented in many instances. All animals died either of shock during the first 24 hours or of complications that seemed to be related to the therapy rather than to the trauma.
3. Normal saline - sodium bicarbonate - serum, intravenously.	
4. Normal saline - sodium bicarbonate, orally, plus serum, intravenously.	
5. Defibrinated blood, intravenously, plus water ad libitum, orally.	

Electrolytic solutions have been proposed by some investigators as a treatment for burn shock. The basis for their use rests on the findings of Cope (1944) in his chemical analyses of burns. Essential electrolytes are lost along with plasma after a severe burn, causing a hemoconcentration to exist in the circulating blood. The blood must then draw electrolytes and fluid from the interstitial (extracellular) space in order to again become isotonic. This causes the interstitial fluid to become hypertonic, and so fluid and electrolytes are drawn from the intracellular space until a chemical equilibrium has been reached. Since the sodium ion and the chloride ion are predominant in the normal extracellular fluid, they are lost to some degree to the blood stream in the shift of fluid. The potassium and phosphate ions are predominant in the intracellular fluid, and the carrying of these ions into the extracellular space in the fluid shift to maintain a state of equilibrium on both sides of the cell membrane creates an electrolytic imbalance. The administration of a sodium ion-containing intravenous solution acts to re-establish the normal electrolytic balance of the body fluid spaces, and, at the same time, relieves the state of hemoconcentration. However, this method of treating burn shock does not replace the lost plasma proteins, so a state of hypoproteinemia must still be treated. Also, it has been found that the use of

massive amounts of electrolytic solutions longer than during the first 24-48 hours postburn is very liable to cause pulmonary edema and death from respiratory failure. (2, 26, 47, 48, 49, 62, 85, 117)

Not to be overlooked in the treatment of burn shock is the use of morphine in large doses. An individual who is severely burned has extremely severe pain, which has been thought by some observers to be a cause of shock. This pain arises from the damage and exposure of thousands of pain fibers, and must be relieved. Under these circumstances, it is not at all uncommon to give one-half grain of morphine sulphate as an initial dose to an adult. Most authorities prefer to give the narcotic as an intravenous injection, since in a state of shock there may be little effect gained from an intramuscular injection because of lack of adequate circulation and then a suddenly increased narcotic effect when the shock is relieved. (110).

VI.
TREATMENT OF THE BURNED AREA.

A. ANCIENT METHODS OF TREATMENT.

Burns have been treated in one way or another ever since the discovery of fire by man. The number of hundreds or thousands of years this has been done is a problem for the historian, but Hippocrates in 430 B.C. advised the following: "Having melted old swine's seam and mixed with resin and bitumen, and having spread it on a piece of cloth and warmed it at a fire, apply with a bandage."

Later, a Greek of unknown name recommended the following formulae: "Boil bean flour and crusts of bread with a cat's penis and smear over the burn. Or roast a handful of barley at the fire and mix it with the oil of roses and the whites of eggs and use as an ointment."

Pack and Davis (1930) describe a salve used by Paracelsus of ancient times. "It consisted of the fat of very old wild hogs and bears heated half an hour in red wine, then dropped into cold water, which was next skimmed and the fat rubbed up with roasted angle worms and moss from the skull of a person hung, scraped off during the increase of the moon, to which were added bloodstone, the dried brain of the wild hog, red sandal-wood and a portion of a genuine mummy." (15)

It is not stated whether or not the patients lived after having been subjected to the use of such a concoction, but it may be presumed that those who lived did so despite the treatment.

B. NINETEENTH CENTURY AND EARLY TWENTIETH CENTURY METHODS OF TREATMENT.

In 1858, Passavant described the use of a continuous warm bath for the treatment of severe burns. This form of therapy was also practised by Hebra in 1861 and

has been cited by authors as being original, but the credit for such a discovery rightfully belongs to Passavant. He recommended that the patient be immersed in the warm water bath so that the devitalized tissues may easily slough away and healing take place as rapidly as possible. For burns around the head he used warm compresses. This method of treatment was very popular until the early 1900's, and modifications of it have been employed and devised as late as in 1944. Passavant also devised the method of classifying burns into first, second, third and fourth degree lesions, a classification which is still used occassionally. (91, 101, 102)

Sollman (1917) spoke very highly of the use of paraffin in the treatment of burns. The use of this substance must also be credited to Dr. Barthe de Sanford of France. (111, 108)

Risley (1920) summarized the treatment of burns at that time and recommended the use of one of the following: The open air treatment, picric acid, or paraffin films. He recognized the danger of sepsis in burns and stated that he believed that burns were candidates for hospital care rather than treatment at home. He considered oily dressings to be contraindicated for the treatment of burns. (99)

C. THE USE OF TANNIC ACID.

In 1925 Davidson first used tannic acid as a means of treating burns. He noted the loss of fluid from the burned surface and the high incidence of toxemia in these patients and was of the opinion that a means of coagulating the skin or burned tissue would be an ideal method of relieving these conditions. His original method of application was to thoroughly clean and debride the area and then apply compresses soaked with a 2.5% aqueous solution of tannic acid. The following advantages of this form of therapy are quoted from his initial report in 1925:

"Coagulation of the devitalized tissue by the use of tannic acid lessens toxemia....Tannic acid as an initial dressing has an analgesic effect...The subsequent use of the open air method causes minimal trauma and promotes general comfort.... The local astringent effect prevents the loss of body fluid...Secondary infection is limited by this method of treatment because of the absence of a favorable nidus for bacterial growth....Scar tissue formation has been lessened....the protective layer of coagulated protein forms a scaffold for the growth of the young epithelial cells over the denuded surface." (31)

The use of tannic acid was a great step in the advancement of better care of burns. The immediate effect of its use was to lower the mortality from burns to a new low figure. It was the best and the ideal treatment of its time and was in use in the Armed Forces even after the beginning of World War II. However, its use is not ideal and is to be condemned if better materials are available.

The most prominent disadvantage to the use of tannic acid is the occurrence of central necrosis of the liver following application of the drug. This may or may not be of a severe enough degree to be fatal, but even non-fatal cases show evidence of liver damage. The incidence of this complication was found by Erb and his associates (1943) to be 61% of all fatal burns treated with tannic acid in their series of autopsies. They also noted that there was no liver necrosis present in those patients who were not treated with tannic acid. These findings have been duplicated by the studies of other investigators and have been attributed by Harkins (1944) to be due to the contact of tannic acid to a moist burned surface for long periods of time. A second objection to the use of tannic acid refers to its failure to prevent loss of fluid in third degree burns, in which the fluid loss consists mainly of the "white hemorrhage" of Koch and Allen and is found mostly within the subcutaneous tissues in the form of edema. Another serious fault in the use of tannic acid is that the eschar which is formed is the result of the precipitation of protein materials at the site of the burn. This action is said to delay healing of the wound because small islands of viable epithelium remaining after the burn are destroyed and thus are not available for use in the regeneration of the skin overthe area. (5, 39, 59, 69, 77, 79, 105)

D. PRESENT-DAY METHODS OF TREATMENT.

The methods of treatment of thermal burns at the present time are many, varied, and seem in many instances to depend on the whims and fancies of the individual operator. In 1944, one investigator of the general problem listed seventy-five different methods of treatment which were in use and advocated for use as ideal methods of caring for burned skin areas! This simply serves to indicate the lack of a generally accepted method of treatment which will bring about the best possible results. It would be impossible to discuss all of these means of treating burns without making this paper very bulky and boring, so many of them willbe simply mentioned and many will be left out entirely.(59)

There are many reports in the literature concerning the use of local applications of dyes and escharotic agents to burned surfaces. The basic purposes for the use of such preparations seem to be the formation of an eschar or film to prevent further loss of fluid, prevention of infection, and stimulation of proliferation of epithelium. Examples of these are (1) tannic acid - silver nitrate, (2) gentian violet, (3) gentian violet - silver nitrate, (4) triple dyes, (5) aqueous solutions of various analine dyes, and (6) the use of brilliant green, scarlet-R or other single dyes. Amazing and beautiful end results are reported by the advocates of each method

of treatment. However, other investigators point out that the eschar formed by the application of these materials to an injured surface is the result of necrotization of the surrounding tissue and precipitation of the protein exudation of the wound. Such an action may delay healing and may cause skin grafting to become necessary in a wound which would otherwise have healed spontaneously. Cope (1944) further indicts their use with the following statement:

> "Chemotherapeutic agents other than sulfonamides and penicillin, such as the gentian violet and triple dyes have been recommended for local use on burn wounds. These dyes, at bacteriostatic concentrations, are toxic to tissues and therefore delay wound healing....No chemical agent is known which expedites wound healing above the physiologic pptimun pertaining under the state of normal nutrition and the absence of infection." (26, 3, 4, 12, 14, 19, 23, 59, 77, 86)

Despite the objections to the use of chemotherapeutics on burns, the use of pyruvic acid has been recommended by Connor and Harvey (1944) as a means of promoting early sloughing of necrotic tissues in order that skin grafting can be carried out at the earliest possible time. They have found that the use of this agent causes the tissue slough to be complete in about seventy-two hours after application of the acid in an ointment base. There is no apparent effect of the acid on the surrounding tissues and the resultant base is composed of pink subcutaneous tissue. Since the wound is ready for early grafting, many of the problems of infection, contractures, large open wounds, and continued loss of

fluid through the wound are remedied. However, this method of treatment requires further study and evaluation before its proper place can be determined. (24)

Various ointments, most of them containing one or another of the sulfonamides, have been advocated for local application on the fresh burn. Other means of applying sulfonamides, such as sprays and films, are also in use. The apparent purpose for this method of treatment is the supposition that a high local concentration of a bacteriostatic agent will inhibit bacterial invasion to the degree that secondary infection does not become a problem in burns. Little objection has been raised against the use of sulfonamides in this way and at this time their use seems to be justified. Worthy of mention is the observation that sulfonamides given orally do not prevent infection of the burned area, but do minimize the incidence of generalized infections and septicemia. Penicillin has also been used locally and parenterally in an effort to avert or minimize infection, but results at thistime are inconclusive. (23, 30, 42, 44, 46, 65, 72, 75, 83, 93, 95, 96)

Boric acid is often used as a mild bacteriostatic agent in cases of infected wounds, and it seems to have a beneficial effect in many cases. It must be remembered, though, that boric acid is a toxic substance if absorbed in sufficient quantities, and deaths from boric acid intox-

ication have been reported. This is not the result of a large single dose, but the effect of repeated doses resulting in accumulation of boric acid in the brain, liver and body fat and causing pathologic changes. (92)

The use of pressure dressings on burns is not new, but of late it has assumed a prominent place in the treatment of most burns. The object for its use is twofold in nature: (1) to provide a means of preventing additional fluid loss at the site of the lesion, and (2) to provide a splinting effect for the soft tissues as a preventive measure against the development of contractures. Blair (1924) listed the following advantages of the application of pressure dressings on wounds: (1) elimination of dead spaces, (2) control of oozing, (3) limitation of venous and lymph stasis, and (4) elimination of the amount of plastic material that pours into the wound. In 1933, Luxenberg advocated the use of a pressure dressing and ACE bandages as a means of hastening healing of chronic ulcers and burns. He encouraged his patients to be ambulatory and stated that the pressure dressing acted with a massaging effect which improved circulation when the patient walked. This form of the use of pressure did not gain much popularity. The present-day use of pressure dressings dates from the observations of Allen and Koch in 1942. They recommended that the wound be debrided, washed with neutral soap, covered

with fine-mesh vaseline gauze and then incorporated in a pressure dressing for the prevention of further fluid loss. Very good results have been obtained under this system of therapy and today this ranks as probably the most widely used method of treatment. Revisions of the details of the bandaging have been made by various operators, most notable of which is the use of plaster casts as a means of applying pressure. This was first suggested in the United States by Levenson and Lund in 1943 and was used quite extensively in the later stages of the recent war. (5, 71, 74, 16, 88, 50, 51, 54, 16, 6)

Should fresh burns be subjected to debridement? This question has been debated by authorities during the past several years, with many men claiming that the heat of the burn sterilized the wound and that debridement is not necessary. However, Koch (1944) states that the usual burn seen by the private physician is much different from those seen on board ships or in the case of the Cocoanut Grove disaster. Usually, the burn has already received home-style "first-aid" treatment in the form of the application of greasy ointments, butter, lard, or whatever else is available. Thus, the burn is already contaminated and in need of cleansing in order to render it nearly surgically clean. The severity of thecleansing and debridement is another subject for discussion. Scrub-

bing with green soap and stiff brushes, such as is done in some hospitals, is injurious to the area and may damage the few remaining viable epithelial cells which may be present on the burned area. This is simply adding insult to injury. A better method is to remove all signs of gross contamination and then wash the burned surface, using cotton pledgets or gauze sponges. Following this, irrigation with massive amounts of normal saline is advocated. (69, 68, 88, 40, 5, 110)

Skin grafting is a valuable surgical procedure which isof great importance in the treatment of large and severe burns. The details of grafting will not be discussed in this paper. Skin grafting should be carried out as early as possible in order that loss of fluid may be minimized, serum protein levels kept nearly normal, and contractures be avoided as much as possible. Many different types of grafts may be used, but best results are usually obtained when a split-thickness of skin is used. The graft must adhere closely to the recipient bed in orderto grow, and for this purpose the plasma-thrombin technique of grafting has been developed by Young and Fovata (1944) and is commonly used today. It has been found that homogenous and heterogenous grafts may be used as a means of supplying temporary skin coverage, but these grafts do not "take" and eventually

have to be replaced by the patient's own skin. However, they may be life-saving measures in some instances. Skin grafting of old unhealed burns should not be attempted until such time as the patient is in fairly good physical and nutritional condition, and, above all, not unless the serum protein level is nearly normal. Otherwise, the grafting will not be successful. (5, 13, 17, 20, 21, 35, 38, 45, 67, 80, 90, 98, 113, 119)

VII
COMPLICATIONS OF THERMAL BURNS

A. Renal Pathology.

Probably the most important complication of severe burns within the first few days following the injury is that related to renal damage. It is dangerous in that nothing can be done if the damage is severe enough to cause anuria. In less severe cases there may be found a persistent oliguria, azotemia, decreased urinary nitrogen excretion, albuminuria, and hemoglobinuria. These are clinical signs of impaired renal function and, along with the appearance of casts in the urine, indicate a greater or lesser degree of kidney damage. Possible causes for this include the state of shock, increased fragility and hemolysis of the cellular portion of the blood, and the production of a toxin at the site of the burn. The state of shock causes a decrease in the effective filtration pressure in the afferent arterioles of the glomeruli and a consequent decrease in the excretion of urine. It is the opinion of some investigators that the heat at the site of the burn causes destruction of some of the cells of the blood and an increased fragility of the blood cells in the neighboring capillaries. This causes hemoglobin to be liberated in the circulating blood and filtered out by the kidney. The opinion is also expressed that there is a toxin produced at the site

of the burn and that this toxin causes pathological changes in the kidney. As support for this contention, the investigators state that the renal complications become more prominent in burns which are of great severity. (109, 87, 64, 53, 22)

The microscopic picture presented in cases of renal damage is that of hemoglobin precipitation in the glomerular spaces, tubular degeneration, and the appearance of hemoglobinuria, casts in the urine, and oliguria. Erb and his associates (1943) reviewed autopsy findings in a series of sixty-one fatal cases of burns and found that the incidence of kidney damage was much higher in those cases treated with tannic acid. Shen and Ham (1943) stated that those patients who have hemoglobinuria after a severe burn usually show a chronic azotemia of moderate severity in spite of adequate restoration of fluid volume or urinary excretion. Early in the course, blood studies show a retention of non-protein nitrogen, but in the usual case this is soon reversed to a situation of increased urinary excertion of these materials. This is one of the factors which causes the patient to exhibit a negative nitrogen balance. (39, 109, 22, 53, 64)

The treatment for renal damage is really non-specific and consists of the relief of shock and the adminis-

tration of an adequate fluid intake. Nothing more can be done.

B.
TOXEMIA.

After the state of burn shock has been conquered in a severe burn there is still a very dangerous period during which the life of the patient may be very much endangered. This is the state of acute toxemia and usually occurs in 48-72 hours after a burn. It is very adequately defined by Van Duyn (1945) in the following statement:

> "Acute toxemia (toxic shock) is that phase of a burn characterized by drowsiness or semi-coma, high fever, rapid pulse, rising non-protein nitrogen level of the blood and diminished urinary output. The blood pressure is lowered as in secondary shock. There is frequently nervousness marked by restlessness, vomiting, hiccup, and convulsions. During the toxic period there are disturbances in hepatic function, and jaundice may be present." (115)

The causefor the development of toxemia following burns is not thoroughly agreed upon by those who have investigated the problem. All are agreed that there is an absorption of some product from the burn site, but some state that this product is split-protein in nature and others believe it to be a toxin produced by bacterial contamination. At any rate, there are organic lesions found in the brain, liver, kidney and other organs of those persons who have died of toxemia. Harkins (1942) believes that burn toxemia is related to a disturbed hepatic function, since it is accompanied by jaundice

and abnormal response to hepatic function tests. He does not state that liver damage is the cause of death in cases of burn toxemia, but his statements leave one with that impression. Certain others believe that central nervous system changes, consisting mainly of severe cerebral edema and ganglion cell changes in the hypothalamus, are responsible for death at this time. (56, 33, 3, 42, 106, 115, 116, 7, 9)

The treatment of burn toxemia consists of supportive therapy. Infection must be combatted, adequate fluid intake provided, and convulsions controlled. (76)

C. Hypoproteinemia and nutritional problems.

Every severely burned patient immediately becomes a candidate for the occurrence of hypoproteinemia and a severe nutritional problem unless some means of adequate protein intake is supplied early in the course of his treatment. There is extensive loss of nitrogenous products through oozing of the lesion and through increased excretion in the urine. There is also an increased demand within the body for nitrogenous products to be used in the building of new tissue for healing of the burn. Together, these factors make a negative nitrogen balance an almost certainty. With continued loss of nitrogenous products the serum protein level is decreased to a dangerously low reading, and healing of the burn becomes impossible. The human body normally has a reserve of

about two kilograms of protein which is deposited in the liver and subcutaneous tissues and which can be mobilized rapidly in case of severe protein loss. However, in cases of severe plasma loss this amount of protein is soon depleted and some external source of protein must be supplied. Most patients who have suffered severe burns have very poor appetites and this makes the ingestion of a high protein diet very difficult. To further complicate the problem, Co Tui and his associates (1944) found that at least 1,000 grams or more of meat is necessary in the daily diet of a patient who has a burn covering 10% or more of the body surface in order to maintain the patient's present state of nutrition or to gain any ground toward raising the serum protein level. Obviously, a patient who has a very poor appetite will fall far short of this amount in his ingestion of protein-containing foods, and some other means must be employed in order to insure adequate intake of essential amino acids. The use of intravenous solution of amino acids or hydrolyzed proteins (Amigen, Parentamine) and the feeding of high-protein formulae by intubation procedures have been found to be the most successful methods of combatting the nutritional problems in the early stages following a severe burn. Large amounts of protein may be administered by these routes and, as the patient's condition improves, they can easily be used in conjunction with a diet

which is appetizing to the patient. (28, 1, 23, 112, 114, 118, 36, 84, 64)

Although mention has been made earlier in this paper, it is essential that skin grafting be carried out as soon as possible following a severe burn. This decreases the loss of protein-containing exudate and lessens the possibilities of the appearance of severe malnutrition. (32)

D. Pulmonary burns.

Although pulmonary burns occur in a rather high incidence in cases of severe burns, their presence and importance is often overlooked. Aub and his associates (1943), in studying the pulmonary complications of the burns of the victims of the Cocoanut Grove fire, found little correlation between the severity of the surface burns of any one patient and the pulmonary damage which was present. They were unable to make an accurate estimate of the extent of the pulmonary burns until the patient had been under treatment for some time. However, they noted that all of their patients showed at least one of the following symptoms and signs suggestive of pulmonary injury:

1. Burns around the mouth and nose.
2. Cyanosis, dyspnea and restlessness.
3. Extreme dyspnea and occurrence of rales.

4. Edema and reddening of tissues beyond vocal cords on laryngoscopic examination.
5. Signs of diffuse bronchiolitis.
   A. Localized lobular collapse.
   B. Acute emphysema, especially in apices.
   C. X-ray findings of emphysema and lobular collapse.
6. Diminished vital capacities.

These findings agree with those mentioned by more recent observers, and occur within the first 24 hours postburn. Although the pulmonary damage may not be of a severe nature, one is always safe in his course of treatment if he provides for adequate intake of air, performing a tracheotomy in cases of acute laryngeal edema, and places the patient on a course of sulfadiazine or penicillin as a precaution against secondary infection and pneumonia. (8, 47, 46, 65)

E. Anemia.

In many cases of severe burning a relatively severe secondary anemia occurs during the convalescent phase. This is thought by some to be the result of actual destruction of red blood cells at the time of the injury, and was prevented to some degree by Evans and

Bigger (1945) by the use of frequent infusions of whole blood. However, little more that this single report is to be found in the literature, so results of this therapy are not conclusive. (1, 41)

F. Contractures.

These are rather late complications of severe burns and are gradually disappearing from the scene as active surgical treatment of the initial injury becomes more common. They are usually the result of the lack of early skin coverage of the burned area and are due to excessive formation and shrinkage of fibrous scar tissue. If left uncorrected, they cause orthopedic deformities and permanent crippling of the individual. The methods of correction may be excision of the scar and skin grafting of the area or the use of any of the many plastic surgical procedures. Neither procedure should be attempted until the patient's physical and nutritional condition is as nearly normal as possible. (32, 17)

G. Ulcers of the gastro-intestinal tract.

These lesions, commonly seen in past years, are now becoming rather rare complications of severe burns. Although they were first reported by Long (1840) and Cooper (1839), it was Curling (1842) who described the ulcerations in detail and attempted to postulate a cause

for them. He believed that the ulcers occurred in the duodenum because of an impaired function of Brunner's glands. However, since that time the lesions have been found also in the stomach, jejunum, and duodenum and his theory has been discarded. Pack (1926) presented a review of the histopathological findings in ulcers of the duodenum and stated that the outcome of such lesions is perforation, hemorrhage, or spontaneous healing. He made no attempt to explain the occurrence of the ulcers. McLaughlin (1933) produced ulcerations of the mucosa of the small bowel in dogs by partially damaging the adrenal glands, and noted that the time of occurrence of gastro-intestinal ulcerations varied from two to seventeen days after the infliction of a severe burn. Erb and his associates (1943) in a series of autopsies expressed the belief that the ulcerations were probably the result of circulation of some toxic substance in the blood stream. This view is also held by Douglas (1944). Whatever the cause, ulcerations of the digestive tract do occur, but at the present time their appearance is not common. If the ulcers occur on a toxic basis, the present-day methods of combating the toxemia of burns may be the reason for their absence from the general picture presented by a severe burn. (33,25,39,66,73,82, 29,89,94)

H. Burns in diabetic patients.

The presence of diabetes in a severely burned patient adds another factor which endangers his life. The skin normally contains much glycogen and a small amount of glucose, but in a poorly regulated diabetic the ratios are somewhat reversed so that the amount of glucose in the skin is greatly increased. It may be possible to have 20 to 25 grams of glucose in the skin if the blood sugar is high and the diabetic condition under poor control. Injury to the skin causes liberation of this stored glucose into the blood stream, causing an increased blood sugar level. The diabetic may not have enough insulin available for reaction with the increased blood sugar content and may be pushed into a state of diabetic acidosis or coma. The normal person has an adequate endogenous insulin reserve which will be of sufficient quantity to combat any such danger. (100)

VIII.
SUMMARY AND CONCLUSIONS.

1. The problem of the physiology and treatment of severe burns has been reviewed. Special emphasis has been placed on the physiology and treatment of burn shock.

2. Burn shock is the most important and first problem in the treatment of severe burns. Failure to recognize or treat the condition may result in death of the patient. At the present time the use of plasma is the treatment of choice, although the use of electrolytic solutions may also be of value.

3. Tannic acid is undesirable as a treatment for burns because of its high toxicity and its effect of retardation of healing of the local lesion.

4. Although there are proposed many methods of treating the burn lesion the most satisfactory procedure is that advocated by Allen and Koch, or a modification of this treatment.

5. Skin grafting of the burned area should be accomplished as early as possible in order that plasma loss may be diminished, nutritional problems be averted, and the best obtainable cosmetic and functional result be obtained.

6. Complications of severe burns have been mentioned. Means of prevention or treatment of these complications have been presented.

Surgical Procedures in Split Thickness Grafts Using Plasma-Thrombin Technique

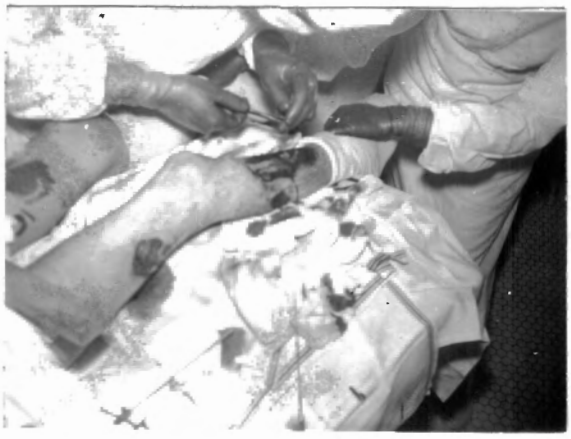


Fig. 1. Debridement of area to be grafted.

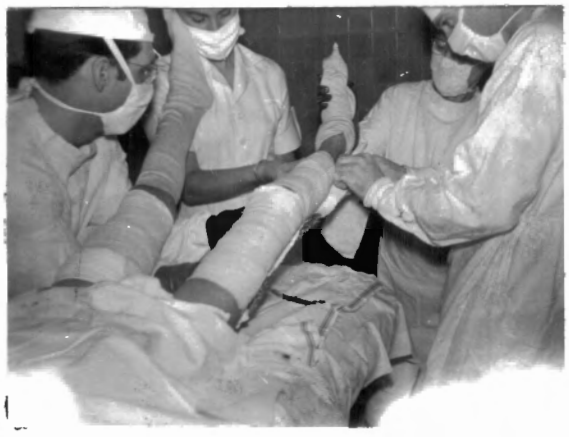


Fig. 2. Application of split thickness grafts.

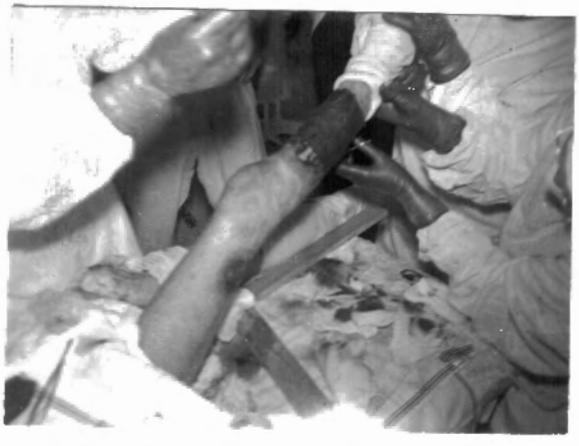


Fig. 3. Initial dressing with fine mesh gauze and scarlet-R.

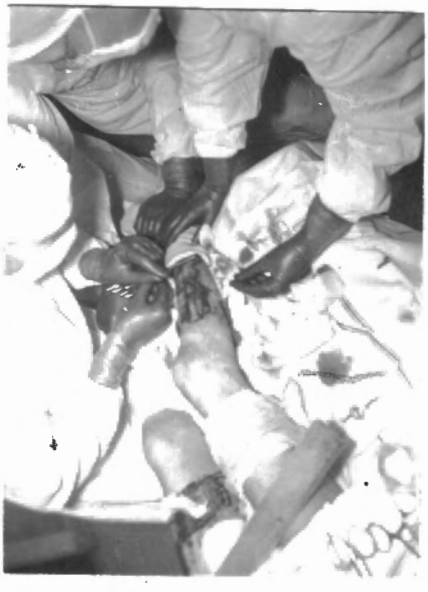


Fig. 4. Application of pressure areas.

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