WRINGER INJURIES OF THE HAND

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Wringer injuries of the hand are of special interest because the extent and severity of damage constitute a real cause of disability and limit working capacity.

MacCollum (1938) was the first to emphasise the characteristic features of the injuries caused by roller-type machinery, coining the term "wringer injuries." Later, Inns (1957) called them "avulsion injuries," applying this term to all injuries in which, regardless of the nature of the trauma, the skin and subcutaneous tissue are stripped or degloved as a flap from the deeper tissues. The skeleton of the hand is also frequently involved. In the review published by Hausmann and Everett (1950) fractures were encountered in 21 per cent of the total. The incidence of fractures in our own series was 28 per cent.

CASE MATERIAL

In four years 458 patients with industrial injuries underwent treatment in the Hand Surgery Department of the Institute of Reconstructive Surgery in Sofia. In ninety-one patients (19.8 per cent) the injuries were caused by machinery with rotating parts. The patients were chiefly manual workers in textile and rubber factories.

In twenty patients the lesion involved only the distal phalanges. Notwithstanding the rather high proportion of the latter group, it is not included in the present review because the isolated involvement of the distal phalanx does not show the particular characteristics of the injuries produced by moving rollers, such as occur when more of the hand is involved.

CHARACTERISTICS OF THE INJURIES

The characteristic features and severity of the lesions are determined primarily by the following factors: 1) the type of surfaces exerting pressure—their texture, hardness and temperature; 2) the distance between the rollers and the speed of rotation; and 3) the duration of trapping of the hand between the rolling mechanisms.

On careful review of individual cases three typical clinical pictures emerge. Partial or total denudation of the hand—This is often accompanied by avulsion of the terminal phalanges. It is commonly caused by smooth, rapidly moving rollers, with a small gap between the rollers—up to one centimetre. Belt pulleys are typical examples of these rotating machines. The lesions are the result of the interaction between two factors: the pulling effect of the roller or belt, and the counter traction applied by the patient, who tries to extract the entangled hand. The clinical picture and treatment in these injuries are determined by the extensiveness of skin loss.

Lacerated wounds with wide flaying of surrounding skin—These are very often accompanied by fractures of the bones (Figs. 1 to 7). These injuries are usually caused by smooth metallic or rubber rollers, with a gap of two or three centimetres between them and rotating slowly. Here, the powerful pressure exerted upon the deep tissues is the basic traumatising factor, resulting in a long-lasting oedema of the hand. The discrepancy between the small size of the wound and the extent of surrounding skin detachment is a typical feature.

Numerous cut injuries of the fingers or the entire hand, with skin avulsion—These are caused by rapidly moving planes, provided with multiple sharp cutting surfaces. A representative of this type of machinery is the carding machine. Not infrequently these injuries account for very severe mutilation of the hand and fingers. Treatment is guided by measures aimed at conservation and survival of affected parts.
Lacerated wound with wide flaying of surrounding skin. The hand of a textile worker of 37 years, injured by a punching machine with smooth heated metal rollers set at a gap of two centimetres. Figures 1 and 2—One hour after injury. Note the extensive flaying of the palmar skin, the crushing of the thenar muscles, the damage to the tendons of the superficial flexor, and the burning of the skin of the dorsum of the hand. The digital nerves were also damaged, the hand was swollen and the fingers were cold. Figure 3—Radiograph showing fractures of metacarpals and intercarpal dislocation. Figure 4—Radiograph after primary operation, showing the fixation with Kirschner wires. Repair was by replacement of flaps after removal of subcutaneous tissues, and by free split-skin grafts. The area of burnt skin survived, but later a necrotic area in the region of the wrist had to be replaced with a free graft. Figures 5 to 7—Six months after injury. The patient has returned to his original work.
Distribution—In the series under discussion the extent of the lesion was classified as follows: isolated involvement of the thumb, five patients; isolated involvement of a finger (excluding the thumb), eight patients; involvement of several fingers, twenty-four patients; involvement of the dorsum or the palm of the hand, nine patients; involvement of the fingers and hand, twenty-five patients.

TREATMENT

All the patients were admitted to hospital. Sixty were operated on within twelve hours of the injury. Four, admitted with gross oedema, underwent operation several days later according to Iselin's principles of the "delayed emergency." The remaining seven patients were admitted after primary treatment in other units.

Of the twenty patients with fractures, fourteen had displaced fractures or fractures and dislocations necessitating osteosynthesis and fixation of the bone.

Out of the total of seventy-one patients, forty required skin replacement as follows: free grafting, with or without a local flap in twenty-three; pedicle flap from a distance in ten; monopedicle tube flap in five; pocket grafting in two. Amputation of the hand was carried out in four cases. In two of these it was inevitable on account of multiple cutting injuries and complete mutilation of the hand. In the other two amputation was performed several days later for moist gangrene.

After operation the hands were immobilised in plaster splints for six to ten days in an elevated position. Rehabilitation after operation was carried out in most of the patients.

PRINCIPLES OF PRIMARY OPERATIVE MANAGEMENT

Three principles were followed in carrying out the primary treatment. They are listed below in the order of application.

*Improvement of blood supply* in the areas with impaired nourishment. This is achieved through derotation of twisted flaps, perforation of flaps in order to reduce congestion; local hypothermia; reposition of fractures and dislocations; reimplantation of skin areas and of greater or smaller portions of fingers attached to the hand by narrow skin slips. We have invariably postponed removal of parts of the hand until demarcation of the necrotic area was obvious. For several days a "wait-and-see" policy is followed. A number of steps are taken to improve the blood supply as follows: intra-arterial or periarterial blocking of the brachial artery with procaine, vasodilators such as acetylcholine parenterally, and elevation of the hand. A substantial number of areas with impaired supply survived. In a few cases the skin flaps developed necrosis in spite of vascular patency, due to the severity of the primary direct trauma.

*Stable fixation of bones* (Figs. 8 to 15)—The statement of Prendiville and Lewis (1955) that "internal osteosynthesis is not a method of choice but rather a method of necessity" is still more valid in the treatment of open fractures in wringer injuries of the hand. Firm fixation improves the nourishment of segments distal to the fracture site. Secondly, it provides a stable bed for skin grafts, and in a number of cases makes external immobilisation unnecessary. Moreover, stable bone fixation allows early mobilisation of the fingers and in this respect plays a decisive role in the quick restoration of function and working capacity. The middle and basal phalanges are fixed by two crossed Kirschner wires. In the metacarpals the fragments are fixed to adjacent metacarpals. Bell, Mason and Allen (1954) emphasised the two most important requirements in the treatment of crush injuries of the upper limb—"clean wound" and "closed wound." We agree with this, but would add a third requirement, namely, "stable wound." We have never regretted using Kirschner wires in fixing the skeleton of the hand, except for instances when the wires pierced joints.

*Primary coverage of the skin wound*—Primary coverage of skin defects is of the greatest importance in saving a severely damaged hand, as has been repeatedly emphasised (Bell et al. 1954, Bunnell 1956, Innis 1957, Blokhin 1960, Dudin 1963, Holevich 1965).

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The effect of stabilisation of broken bones. Figures 8 and 9—Crushing wringer injury of the hand of a 19-year-old man. Multiple small lacerations with detachment of surrounding skin and with exposure of tendons and damage to neurovascular bundles. Figure 10—Radiograph showing intercarpal dislocation with fracture of fourth metacarpal and subluxation of third metacarpo-phalangeal joint. Figure 11—Radiograph showing fixation with Kirschner wires. All skin flaps were replaced, some after removal of subcutaneous tissues. Figure 12—Radiograph showing conditions four months after operation. Figures 13 to 15—The condition of the hand four months after operation showing the stiffness of the fourth and fifth metacarpo-phalangeal joints. The patient resumed his former job.
Treatment of degloving injuries—Our procedure in typical denuding injuries (degloving) of the fingers and hand was as follows:

Skin defects on dorsum or palm of hand—Remaining flayed skin flaps were used, if possible, to resurface the defects and were supplemented by free split-skin grafts. Depending on the blood supply, the flaps were replaced as they were, or with the subcutaneous tissue removed, as suggested by Farmer (1939). With this group of patients pedicle skin flaps were resorted to only when there was no alternative: for example, in extensive wounds with exposed cartilage and tendons. We were able to observe the serious sequelae for the hand in five instances of reimplantation of skin with subcutaneous tissue attached, carried out in another hospital.

Particularly illustrative is a patient who was admitted on the twenty-sixth day after injury and operated on within twenty-four hours. Half of the dorsum of the hand and part of the palm were degloved, with nerves and tendons preserved. At operation the hand was very oedematous. The reimplanted necrotic skin was removed. Subcutaneous granulations with an adequate blood supply were found on the dorsum and palm of the hand, which at many points reached the immediate vicinity of the tendons, with sheath and paratenon showing fibrous alteration. The wounds were covered with free split-skin grafts. They took perfectly along the entire surface. The patient resumed his former job, but there is persistent flexion deformity of the fingers (Figs. 16 to 20).

Degloving of one or more fingers—Whenever neurovascular bundles were preserved and tendons were not exposed free skin grafting was done and good results were achieved. When skin is avulsed, together with the digital nerves and arteries of a single digit, amputation was preferred; it was recommended also by Bevin and Chase (1963). If more than one digit is involved we feel that a "pocket plasty" should be employed. This appears to us to be the only acceptable indication for this particular plastic procedure. We used skin from the opposite arm or thoraco-abdominal region. Our experience with resurfacing of denuded fingers by means of a tube pedicle has been disappointing.

Degloving of thumb—Regardless of the type of denudation, amputation is never considered. This policy is widely accepted because of the importance of the thumb, and because even the best reconstructed thumb is less than perfect. Bunnell stressed that adjacent tissues were the best cover for the thumb, particularly the volar aspect. McFarlane and Stromberg (1962) stated that all kinds and degrees of skin loss of the thumb could be repaired with flaps raised from the dorsum of the homolateral hands. In our opinion the volar aspect of the thumb at least may be covered with a normal sensory flap as early as at the time of primary operation. The flap we use, raised from the dorsum of the index finger, resembles the racket-shaped flap suggested by Holevich (1963), but it is broader and encloses both neurovascular bundles. For the dorsal aspect of the denuded thumb we used free grafts, because local subcutaneous sources were deficient. Sensibility of a flap cut from the dorsal side of the index is not of the quality of the pulp-island flaps described by Littler (1960) and Tubiana, Duparc and Moreau (1960), but it meets the requirements in every other respect. Furthermore, it provides for the covering of almost the entire volar aspect of the thumb which is a real advantage. The other possibility—resurfacing of the thumb with a monopedicle tube and the provision of sensibility at a second stage with an island flap—is only considered secondarily, at least so far as our personal experience is concerned.

Avulsion of both digital and hand skin—In this condition the surgeon is confronted with substantial difficulties. There is wide skin loss. Usually digital nerves and vessels too are avulsed. In these cases placing the hand into a subcutaneous pocket appears at first sight the most acceptable and feasible means of salvage. The operation is simple and rapid, but only so far as the first stage is concerned. The following aphorism is particularly true for the pocket graft in these cases: "The surgeon is invariably familiar with the method of inserting the hand beneath the graft, but he could never say with certainty exactly when and how the separation will be effected."

The enforced position of the hand, the numerous stages
Skin defect on the dorsum and palm of the hand. Figure 16—The hand of a 36-year-old textile worker twenty-six days after a wringer injury. Note the extensive area of necrotic skin representing replaced "degloved" skin. There was a similar area on the palm of the hand. Figures 17 and 18—Ten days after excision of the necrotic skin and replacement with a free split-thickness graft. Figures 19 and 20—Six years after injury. The patient has returned to his original occupation. There is a degree of residual flexion contracture of the fingers.

of treatment, the serious problems involved if infection occurs—all these are drawbacks of pocket grafting. One must also bear in mind the extent of the donor area.

We agree with Holevich (1965) that free skin grafting is much more promising and efficient. Plenty of skin for grafting is available, the duration of treatment is reduced and while the hand is immobilised and elevated the shoulder and elbow can be kept mobile.

When the neurovascular bundles are avulsed with the skin, the finger tips usually undergo mummification, regardless of the plastic procedure carried out, and the interphalangeal joints become permanently rigid. Therefore, we remove the distal phalanges, which have no adequate vascular supply, during the primary surgical treatment, resurfacing the rest of the hand with free split-thickness grafts. At a second stage we trim the grafts on the thumb and first web and replace them with pedicle flaps. As a result of the second intervention, movements of the thumb are greatly enhanced, giving a substantial improvement of the hand grip (Figs. 21 to 28).
Avulsion of the skin of the hand and fingers. Figures 21 and 22—The hand of a 49-year-old man that had been trapped between slowly rotating steel rollers set at a gap of one centimetre. The skin and the neurovascular bundles have been stripped and the distal phalanges of the first, second, fourth and fifth digits have been avulsed. In the third digit the middle and distal phalanges have been avulsed. Figures 23 and 24—After primary operation. The second, fourth and fifth digits have been shortened and the whole area has been covered by a free split-thickness graft. Figures 25 to 28—After secondary repair with a pedicle graft to the thumb and first web. There is good function, with restoration of both pinch and grip.
RESULTS

Sixty-five patients were reviewed up to four years after the operation. Fifty-three, or 81·5 per cent, resumed their former jobs, eight returned to modified work, and four, those with amputation of the hand, were pensioned.

DISCUSSION

Post-traumatic oedema of the hand—MacCollum (1938) noticed that substantial post-traumatic oedema was characteristic of wringer injuries, and that massive fibrosis of subcutaneous tissue might follow. Allen (1941) reported on reduction of the oedema after applying compressive dressings. We are convinced that a light compressive dressing (such as used in free grafting) is the best for the hand.

Innis (1957) observed considerable reduction of post-operative oedema in a series of twenty patients in whom avulsed skin and lacerated flaps were removed and the wound was closed by free grafting.

Post-operative oedema in the hand is not dependent on the method chosen for solving the skin problem. We found that hands that had been completely denuded were almost always free of oedema. Hands with small lacerated wounds and extensive flaying of surrounding skin very often displayed a severe and prolonged oedema. This difference is mainly caused by the different mechanisms of injury—that is, the direction of action of the violence producing the injury. In the first group it acted more tangentially and superficially and was essentially detaching, whereas in the second, the force was directed more obliquely to the deep structures and was further associated with compression, so that fractures were more often caused. Thus the amount of oedema present seems to be directly proportional to the length of time the hand is subjected to the violence, and inversely proportional to the size of the skin defect resulting. The lack of oedema after extensive loss of skin is surely due also to the absence of compression by the remaining skin of the hand, because the injury itself has effected an almost perfect debridement.

Skin grafting—Farmer (1939) considered that avulsed skin could be reimplanted provided the subcutaneous tissue was removed. Prendiville and Lewis (1955) did not utilise such skin; they advocated free transplantation, carried out within a week of the excision over a clean and smooth wound surface, definitive haemostasis being secured at the same time. Innis (1957) removed the flayed skin and all flaps of doubtful viability down to the base and performed free plasty at the same operation. The experience of all these authors was based mainly on avulsion injuries of the lower extremities. However, in skin plastic procedures of the hand a factor intervenes which is not so important in the lower limb. In order to preserve specific sensitivity, the proper skin of the hand should be preserved as much as possible, and grafting from a distant site restricted. Flaps showing a good blood supply may be not only preserved but may also be used to cover adjacent areas which might be more important from the functional point of view. It is prudent to conserve doubtful skin flaps, because experience shows that in most cases of wringer injuries of the hand they survive. When the subcutaneous tissue of such doubtful flaps is removed they behave in their periphery almost as free grafts. Similar " pedicled free grafts " conserve a certain degree of sensibility and their reinnervation is quicker than that of ordinary free transplants. In the hand, reimplantation of the proper skin (after removal of the subcutaneous tissue) is expedient, both from the functional and cosmetic points of view. I have carried out this manoeuvre on several occasions in cases where the skin was not too severely damaged.

Free grafting with maximal utilisation of available adjacent flaps should be the primary treatment in wringer injuries of the hand. I am convinced that in the past I have used the distant pedicled flap, with its well known cosmetic and functional shortcomings, too often, and in fact, only an insignificant number of the patients really require such a plasty. I feel that even in total denudation of the hand with avulsion of digital neurovascular bundles, the most
reasonable means for wound closure is the free graft. An important question emerges in the course of treatment of similar skin and digital neurovascular avulsions of the hand: which is to be saved—the width or the length of the hand? In my opinion, for functional purposes, the preservation of the width is preferable. The working capacity of the hand is greater if part of the length is sacrificed to preserve the width of the hand. An obvious improvement of the mobility of the thumb and index finger and, therefore, of the prehensile power of the hand is noticed when the free graft on the thumb and first web is replaced by a pedicle flap. Substitution of the free grafts in the remaining fingers is superfluous and unrewarding.

**SUMMARY**

1. In a series of seventy-one patients with wringer injuries of the hand three basic types of lesion were observed: a) denuding of part or of the entire hand, usually accompanied by avulsion of the distal phalanges; b) small lacerated wounds with wide detachment of surrounding skin and frequent fractures; c) multiple cut injuries of digits or the entire hand with skin avulsions.

2. Treatment was guided by the following principles: a) improvement of blood supply in regions of impaired nourishment; b) stable primary fixation of bones with Kirschner wires; c) primary wound closure through free skin grafting with maximal utilisation of available flaps.

3. Surgical technique as applied in various typical cases is outlined.

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**REFERENCES**


