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HAND RECONSTRUCTION

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The purpose of this review is to highlight the recent advances in reconstruction of the hand. If hand surgery has progressed in the course of the last few years, it is due to a combination of factors of which the most important seems to us to be the individualization of this field. This does not imply a separation of hand surgery from general reparative surgery, but rather an adaption of the most recent biological and surgical advances to the needs of this essentially mobile and sensitive organ.

Only a few years ago hand reconstruction was confined to the domain of traumatology. Now, several new fields have opened, so it is necessary to consider separately at least:

- Reconstruction of the traumatic hand
- Reconstruction of congenital malformations
- Reconstruction of the rheumatic hand
- Reconstruction of the paralytic hand.

Each of these subjects could be expanded upon, but it is not possible to discuss all these topics. We would like to consider first the guiding principles of hand reconstruction and then, using selected examples, demonstrate the most recent techniques used in the surgery of joints, tendons, nerves and vessels of the hand.

For any hand reconstruction, no matter what the aetiology, one must establish a therapeutic plan which considers not only the local lesion but also the state of the whole limb and of the other hand, and the general condition of the patient. The purpose of reconstruction is not so much to restore the anatomy as to restore that function which is the most useful in each case. Treatment for one person is not necessarily the same for another, even though their lesions may be similar.

Bunnell & Boyes have summarized in five steps the plan of repair

(Boyes 1970). It consists of: 1) Skeletal alignment, 2) Skin cover, 3) Restoration of mobility, 4) Restoration of sensibility, and 5) Restoration of the functional position of the hand in relation to the arm. Such are the guidelines which constitute the framework for hand reconstruction. They were formulated years ago and are still valid.

Within this framework, considerable progress has been made. Some advances have resulted from purely technical advances but these alone, although appealing to the surgeon and in themselves important, are not the whole answer. In fields such as control of cicatrization, the restoration of gliding planes, or axon regeneration, which at the level of the hand are of great importance, we are only beginning to understand the sequence of biological events. The mushrooming of fundamental research in functional anatomy, neurophysiology, biomechanics and biology has already influenced and modified more and more our therapeutic attitudes. In particular, the development of new industrial synthetics well tolerated by the organism has opened up some promising new surgical approaches.

Of the synthetic materials used in hand surgery, organic silicone has gained increasing importance. Silicone rubber implants, which are malleable, resistant and non adherent to surrounding tissues, have found wide application in the restoration of mobility of the fingers.

RECONSTRUCTION OF JOINTS

For finger joints, resection arthroplasty, though giving appreciable benefit, achieves mobility at the expense of stability. Articular prostheses seemed the logical answer. The first ones used by Brannon & Klein (1959) and Flatt (1960) were metallic. These implants, whose consistency and rigidity were harder than those of the surrounding tissues, not being cemented into the bony shaft, often caused wear and resorption of the bone, and even fracture. Today, implants totally or partially made of silicone are the most widely employed. There are several models which reflect the different biomechanical concepts.

For Swanson, who, since 1962, has studied the use of implants at various levels in the hand, the flexible implant is a dynamic spacer used as an adjunct to resection arthroplasty (Swanson 1973). Stability after arthroplasty depends not only on the implant itself but also on the formation of a new fibrous capsule which develops around the implant (the encapsulation concept).

Niebauer (1971) perfected a flexible implant whose intra-osseous shafts are covered with Dacron. The surrounding tissue infiltrates into the Dacron mesh, thus fixing the extremities.

Calnan & Reis (1968) studied a polypropylene implant with a particularly thin hinge designed to diminish resistance. Nicolle (1973) added a silicone capsule to prevent invasion of fibrous tissue around the joint mechanism.

Finally it was logical to apply to the hand the experiences gained from joint prostheses in the lower limb. Arthroplasties were developed along the lines of the Charnley low friction arthroplasty principle using metal against polyethylene joint surfaces, and stem fixation with cement. This solution was adopted by Stellbrink (1968) for the fingers (St. George Prosthesis). The principle is probably most suitable for the more complex joints, such as the first carpo-metacarpal or the radio carpal ones, as will be mentioned later.

This review will not cover the technique of fixation of these implants nor give a detailed analysis of the results. We refer to statistics already published (in particular, Swanson 1973 and Bedeschi & Luppino 1974).

In my experience, the Swanson type prosthesis which we have used since 1968 is most useful for suppressing pain in rheumatoid arthritis at the M.P. and I.P.P. joints. Correction of deformity depends more on the musculo-tendinous balance one obtains than on the implant itself. Stability depends on the technique used: we construct a lateral collateral ligament at the M.P. and I.P.P. joint levels of the index and middle finger to resist the pressure of the thumb. Recovery of mobility is more unpredictable than relief from pain and depends on the state of the motor muscles, early physiotherapy and patient's determination. Complications, so far, have been few. Early dislocations and fractures of the prostheses are related to technical errors of insertion or to excessive stress by the patient, especially in heavy people using elbow crutches. Because the stems of Swanson's finger implants remain loose in the shafts, the risk of fracture is reduced, and their removal and replacement, if required, is a fairly simple procedure. However, it is becoming evident that the incidence of fractures is increasing with time.

Results of implants after traumatic lesions seem to be less favourable, probably because of the associated scar tissue. Their use for M.P. replacement in stiffness after burns or interosseous paralysis is a last resort.

For the trapezo-metacarpal joint we have several prostheses at our disposal. For example Kessler (1973) uses a silastic interposition between the metacarpal and the trapezium. Swanson totally excises the trapezium and replaces it with an implant plugged into the metacarpal. The stability of this new trapezium will depend on the depth of the cavity and the method of repair of the capsule. To avoid subluxations, which are not rare, one should reinforce the capsule with a local tendon transfer. We prefer the flexor carpi radialis.

Caffiniere's prosthesis (1972) consists of a trapezium cup of polyethylene which articulates with a metallic sphere mounted on a metacarpal stem. The two pieces are cemented in place before being articulated in the fashion of a total hip prosthesis.

The indications for the various types of prostheses are still vague. There are some cases where the trapezium has collapsed and the cavity created after removal of the trapezium would be insufficient to assure satisfactory stability of the implant. We feel this would be an indication for the Caffiniere's type of prosthesis. We have in fact inserted such a prosthesis into the distal extremity of the radius following carpectomy.

Thanks to the modern trapezio-metacarpal prostheses, arthrodesis of this joint is now rare. Arthroplasties are indicated not only in rheumatoid arthritis and rhizarthrosis but also in cases of post traumatic stiffness or after thumb paralysis. We have combined these arthroplasties with pollicization or phalangization of the first metacarpal. But these arthroplasties remain inadequate for reestablishing mobility of the first ray, a) in the presence of contracture of the soft tissues of the first web, and b) if there is hypermobility of the metacarpophalangeal joint which interferes with the reeduction of the proximal arthroplasty.

Stabilising the M.P. joint by capsular repair or arthrodesis combined with freeing of the soft tissues is indispensable for a good result. All stages can be completed at one operation if there is adequate skin cover, but it often is preferable to separate these steps.

For the carpus, Swanson has designed silicone implants to replace the scaphoid and lunate. These implants, which act as "spacers", are well tolerated biologically and mechanically. Their stability depends on the reconstruction of a strong capsule. They must be implanted before the arthrosis has involved too many carpal and radio carpal joints. In cases of simultaneous lesions of the scaphoid and lunate, Michon (1973) has developed a scapho lunate monoblock implant.

At the radio carpal joint, we have embarked upon wrist arthroplasty with considerable reluctance because we know the importance of stability at this joinf, the most proximal in the hand. This is why arthrodesis has been done so frequently, especially for post traumatic lesions. The functional results are satisfactory in unilateral lesions provided that the muscles of the forearm are little disturbed. It is different if the extrinsic muscles of the hand are insufficient or contracted because of scarring ischaemia or paralysis. Preserving flexion and extension of the wrist reinforces the action of the muscles spanning the joint and so results in an active tenodesis. Stiffness of the wrist is a serious handicap when bilateral, especially in extension, because the patient is not able to attend to toilet functions. Bilateral wrist lesions are frequent in rheumatoid arthritis and it is especially in these patients that arthroplasties have been performed.

Various types of prostheses have been proposed and probably have different indications. The most ambitious types envisage recovery of flexion, extension and even lateral movement (Meuli 1973, Gschwend & Scheir 1973). Swanson uses a flexible silicone implant whose stems slot into the radius and third metacarpal, while Jackson (1975) advocates an interposition arthroplasty using a 3 mm thick silicone disc. This is inserted between the joint surfaces of the radius and the carpus. There is minimal bony resection and the results are encouraging regarding patients afflicted with rheumatoid arthritis in whom one is anxious to relieve pain and preserve some active mobility.

Many other models of joint implants are under study. The best anatomical replicas are not, of necessity, the most useful. It is probable that no definite prosthesis has yet been found, and thanks to biomechanical research and its clinical applications, all current models will be modified with time.

The restoration of mobility at various levels in the hand requires not only mobile and stable joints, but also active motor muscles and the recreation of gliding planes so that the tendons may move.

REPAIR OF TENDONS

Tendon repair is one of the most common and yet one of the most deceiving surgical operations in the hand. Only by thoroughly understanding the healing mechanism of tendons is one able to obtain satisfactory results of repair. In the past few years, thanks to the electron microscope, it has been shown that the invasion of fibroblasts comes from the periphery, and not from the extremity of the tendons, as was previously thought. Adhesions are therefore inevitable and any attempt to impede these normal adhesions will interfere with the physiological repair (Potenza 1964, Lindsay 1960). However, one must ensure that no excessive adhesions result from the traumatic surgical repair.

Movement of the repaired tendon is facilitated by a remodelling of the scar tissue,but we do not understand the mechanism of this process. It is difficult to explain why the scar adjoining the tendon ends remains solid and yet the peripheral scar adhesions become soft and allow movement. To understand this phenomenon a more intimate knowledge of the processes of synthesis, maturation and degredation of collagen is required. Research is in progress to study the factors capable of influencing this cycle so that they can be controlled pharmacologically. Several such investigations have been undertaken and results in clinical applications already are encouraging (Peacock & Madden 1969, Bora 1972).

The long-standing division between the advocates of primary and secondary repair belongs now to the past. No longer is there a basic objection to primary tendon repair as a concept. *Primary repair,* as Verdan has shown since 1952, can often be performed even in the so-called "no man's land" provided that the technique is meticulous and precise and the local conditions acceptable. Advances have been made in both primary and secondary repair. In primary flexor tendon repair, no longer is routine excision of the superficialis tendon advocated. Its ablation inevitably tears the mesotendon and interferes with the vascularization. At present we have become more conservative, preserving both profondus and superficialis tendons when possible (Verdan & Crawford 1971) and limiting the excision of the fibrous sheath, which is of considerable importance mechanically. Kleinert (1975) has developed a technique of primary tendon suture using a protective splint which allows early passive mobilization.

With regard to secondary repair, preserved tendon grafts have been under investigation for a long time and enable us to have tendon banks.

Iselin et al. (1963) developed the use of acellular grafts preserved in a mercurial solution of cialit. Seiffert & Schmit (1971), using labelled isotopes, showed their progressive substitution by collagen.

For many years Peacock has experimented with flexor tendon transplants using gliding appendages taken from fresh cadavers. This method has been used successfully in humans (Peacock & Madden 1967, Hueston et al. 1967) and one can now envisage human composite flexor tendon allografts.

Other easier methods have been perfected to reestablish planes of gliding. Years ago, experiments were carried on to build up gliding canals for tendons, by inclusions of foreign bodies of glass or metallic rods (Mayer & Ransohoff 1936). On the biological plane these attempts have been a failure because of the foreign body reaction, which merely exacerbated the formation of new collagen with its associated detrimental effects on tendon gliding. With the introduction of the almost inert newer substances such as silicone, the problem has been reconsidered (Carroll & Bassett 1963). Hunter (1965, 1971) proposed the principle of forming a new tendon sheath in response to a gliding tendon prosthesis (stage one) followed by the tendon grafting (stage two). This implant is fixed at the level of the distal extremity and pulleys should be constructed at the required levels without fear of adhesion formation. The great advantage of this technique is the creation of a tunnel which at the second stage of the procedure is not reentered except at its proximal and distal extremities. This is the favoured method of tendon grafting in less than optimum cases. It can also prepare the bed for tendon transfers when there is considerable scarring.

One cannot enlarge here on tendon transfers, a subject which has been particularly brought to our attention over the last few years (Tubiana 1969, 1974). However, one should be aware of the many types of tendon and muscle transfers, tenodeses and capsulodeses devised by Zancoli (1968), Littler (1964), Brand (1974), Riordan (1974) and Parkes (1973) which have enabled immunerable paralysed hands to be rehabilitated.

MICROSURGICAL TECHNIQUES

Meticulous technique is paramount if one expects satisfactory results in surgery. To this end, magnification is not an admission of blindness but the acceptance that if you can see what you are doing you have a better chance of doing it well. Thus, low power magnification with loupes is now a mandatory tool in the hand surgeon's armamentarium. It aids accurate atraumatic handling of tendons and other tissues.

Although the advantage of the microscope in surgery has been appreciated for many years, first by otolaryngologists and later by neurosurgeons, its use in peripheral nerve and hand surgery is a very recent phenomenon (Smith 1964).

It has opened the door to a fascinating new world which has caught the imagination of surgeons everywhere.

Microsurgery of the upper limb is used in three capacities: 1) microneural surgery, 2) microvascular surgery and 3) microlymphatic surgery.

1) Microneural surgery

Unreliable and generally disappointing results of peripheral nerve surgery led logically to attempting more accurate alignment of the nerves' component parts. Each nerve consists of an outer fibrous sheath (epineurium) which encases fasciculi or bundles of nerve fibres. Each fasciculus is encased in its own sheath of perineurium and contains, on an average, 10,000 myelinated and unmyelinated axons, all of which are embedded in an interstitium of connective tissue called the endoneurium. It is obviously fallacious to expect to be able to align each of the component parts, for indeed the median nerve in the forearm contains 20–40 funiculi and the ulnar about 20. This means that almost half a million axons are present in the median nerve.

The microscope has enabled us, however, to progress one step further anatomically and permits accurate alignment and suture of, in some cases, individual fasciculi, but mostly of groups of fasciculi. The groups are matched according to shape, size and number of fasciculi within the group.

Blood vessels in the epineurium are a further aid to orientation, espicially in primary repair as is the mesoneurium. A knowledge of cartography is important for this accurate alignment because, stated negatively, pairing a motor with a sensory fascicule guarantees failure. Millisi et al. (1972) have shown that the scar tissue of a neuroma is derived from the damaged epineurium. To prevent this he advocates stripping the epineurium away from the suture line and minimum sutures (one stitch per fasciculus or group of fasciculi). He has convincingly shown that tension at the suture line causes scar formation. This results in a mechanical block to the passage of axons. The value of temporary joint flexion in overcoming tension is of short duration because secondary scar formation develops once normal posture is resumed and this causes constriction and even division of the axons. To prevent tension the only satisfactory solution is the nerve graft. "Axons grow through two anastamoses without tension more readily than through one with tension. With the arm in the neutral position a gap of greater than 2.5 cm after the nerve ends have been dissected free requires grafting" (Millesi 1972).

Finally, magnification is of great benefit wherever interfascicular neurolysis is considered necessary. With magnification and the new techniques of nerve suture and grafting, renewed interest has been directed to the surgery of brachial plexus lesions previously considered hopeless. Narakas (1972), Samii (1975) and Millesi et al. (1973) report some encouraging results.

2) Microvascular surgery

A. Replantation. For centuries the dream of replantation of tissues had remained mythology until the almost fairy-tale reports of limb and digital reimplantation from China reached the outside world. This stimulated much research into the technique of suture of small vessels (Buncke & Murray 1971) and some sporadic reports of clinical replantation appeared (arm: Malt & McKhann 1964), (digit: Tamai 1968).

It is now possible to obtain consistently high patency rates following anastomosis of vessels as small as 0.5 mm in diameter. The exact technique is debated, but in essence it involves resecting the vessel ends back to normal tissue, peeling back the filmy periadventitial tissue and irrigating with heparinized saline, taking extreme care not to damage the intimal lining. In some circumstances gentle dilatation of the lumen with blunt-nosed jeweler's forceps is advantageous, especially if the vessel is in spasm. The vessels are then approximated by the use of a double clamp and sutured together, usually by the 120° triangulating technique using 10-0 or finer round bodied nylon monofilament suture. A vessel of 0.7 mm diameter will usually require 6–8 interrupted sutures. Before the release of the clamps the anastomosis is temporarily wrapped in a plastic strip to prevent excessive blood loss. Blood is also a potent cause of spasm. Various topical and systemic agents have been used to prevent platelet coagulation at the anastomosis site. Whether they are of practical value clinically is difficult to prove. The technique of venous anastomosis is essentially the same, except that veins have much thinner walls, are usually larger, require more sutures and collapse, with the resultant danger of catching the posterior wall with the anterior stitch. Immersing the vessel in water will often float the walls apart and facilitate suturing. Interposition vein grafts solve the problem of the artery whose ends are too far apart to anastomose.

Replantation of digits became the kindergarden training ground for microsurgeons and large series were soon documented, especially in

China, Japan and Australia (O'Brien & Miller 1973, Lendvay & Owen 1970).

Initially, reimplantation of amputations of all fingers were attempted with varying degrees of success. Avulsion and severe crush injuries had universally poor results.

It is generally accepted that *primary repair* of all structures is preferable (one artery and two veins, nerves, tendons and bone), since any secondary surgery may well impair the vascular supply. The bone is shortened slightly. The patient is heparinized for 2 weeks, by which time collateral venous circulation is well established (Chinese Medical Journal) and the digit can survive permanently.

The long term prognosis is not clearly defined, but return of sensation has been surprisingly good. In a series of 61 digits (O'Brien, MacLeod & Morrison, personal communication) none had neuroma problems, all had protective sensation and the two-point discrimination ranged between 3 and 10 mm. When a joint is damaged, movement obviously will be permanently impaired. Tendon movement has been reasonably good.

After many man hours spent, after several failures, after a more careful balance between the anaesthetic risk, the time spent in hospital and the real benefit for the patient, a new, much less enthusiastic pattern of indications seems to emerge for the reimplantation of fingers.

The reimplantation of the thumb remains a major indication; so are multiple amputations, especially the ones of the guillotine type, which have a better chance of success. Lesser indications are the reimplantation of the single amputated index finger, reimplantation of single digits in children, reimplantations for cosmetic reasons.

Reimplantation of hands is most worthwhile, with excellent return of sensory function, and although motor return is often poor (combination of poor nerve regeneration and ischaemic muscle), tendon transfers can complement this deficiency. Amputations more proximal have not been a great success because of their greater muscle content and the greater distance that must be travelled in nerve regeneration.

B. Chronic ischaemia. Many hands have become functionally poor because of poor blood supply (post traumatic). Although viable, they are constantly plagued by cold and paraesthesia. Arteriograms may demonstrate a cause that can be remedied, and vein grafts can be used to bridge large arterial defects.

C. Venous insufficiency. In the classical ring finger degloving injury where the skin has not been completely avulsed, the situation is often that the arteries are intact but the venous drainage has been completely cut off. The skin envelope of the finger becomes turgid with congested blood, and unless venous anastomosis is performed, retrograde arterial obstruction will occur with resultant loss of the finger.

D. Free flaps. Large tissue defects of the arm and hand requiring flaps can be covered by free flap transfer using microvascular anastomosis. This avoids prolonged immobilization in a position deleterious to hand function. It enables immediate post operative elevation, physiotherapy and avoids secondary operations.

Sensory free flaps can be used to reinnervate areas of the hand. The usual donor sites are the first and second web spaces of the foot.

Reconstruction of the congenital and traumatic hand may be managed by toe to thumb or digital transfer.

Free innervated muscle transplant may be used to activate the arm.

3. Microlymphatic surgery

Although in its infancy, microlymphatic surgery is now able to achieve a high rate of long term patency of lymphovenous anastomoses in dogs (Gilbert 1975). One clinical case of lymphoedema of the arm has been reported in which lymphovenous anastomosis was done with dramatic results (Sykes & O'Brien, personal communication).

In summary, microsurgery has opened new prospects in the field of hand surgery by the developments in neuro, vascular and lymphatic surgery. The final perspective in terms of justifiable operating time indications and results are not yet entirely clear.

SUMMARY

To conclude, one must apologize for having introduced so many subjects and left so many loose ends. Hand reconstruction poses a multitude of problems which are presently in an evolutionary phase. In discussing the notion of hand surgery specialization one draws upon orthopaedic, plastic and microsurgical techniques. But is it not precisely this adaption of diverse techniques to one organ which constitutes a speciality?

Rapid progress in hand surgery was achieved the moment surgeons confined the major part of their activities to the treatment of this organ. But let us repeat that progress implies collaboration and not isolation. Advances highlighted in this review resulted mostly from

collaboration between the laboratory and the operating theatre. It is worthwhile creating hand centres not only for the benefit of patients but also for research and for training surgeons. These centres must become places of collaboration between numerous clinical and pre-clinical specialities: namely orthopaedics, traumatology, plastic surgery, rheumatology, neurology, physiotherapy, and applicance makers, as well as biologists and anatomists, all applied to the reconstruction of the hand.

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