FINGER JOINT RECONSTRUCTION AFTER MUTILATION OF THE HAND

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Mobility of the fingers plays a fundamental role in hand function. In cases of fractures or fracture-dislocations, accurate acute reduction and stabilisation, followed by appropriate mobilisation are the most effective means to avoid post-traumatic arthritis. A more challenging situation is major cartilage and bone loss, associated with skin and extensor tendon lesions, a not infrequent situation due to the thin dorsal protection of the proximal interphalangeal (PIP) and metacarpo-phalangeal (MP) joints. The two joints are critical areas for hand function, justifying sophisticated attempts at reconstruction, especially when multiple fingers and multiple levels are involved. However, despite numerous techniques available for reconstruction, very few if any yield an ideal result, a painless, stable, strong, durable joint with full range of motion and, in children, potential for growth. As concerns mobility, Hume *et al.* (30) have recently stressed that daily activities require 60° of movement for PIPJ and MPJ and 39° for DIPJ.

The alternatives for treatment of damaged joints include amputation, fusion, prostheses, spacers and either non vascularized (NVJT) or vascularized (VJT) joint transfer (free or island). The first two options sacrifice the joint but remain acceptable choices in difficult situations.

Finger amputation is rarely indicated for isolated damage but must be considered with isolated mutilations of a single finger, when complex associated lesions compromise ultimate survival and function.

Fusion can afford relief of pain with stability, durability, and strength, but at the expense of mobility. Arthrodesis may still be acceptable, in adults, for some localisations (such as MPJ or carpometacarpal joint of the thumb or the DIPJ), or for isolated finger PIPJ or MPJ damage. However, it must be avoided when multiple fingers or joints are involved.

Among the techniques of fusion, we would stress a useful "salvage" operation that we called the "scaffold" operation (19). With major metacarpal loss, involving the MPJ of a central single ray it is possible to "fuse" the base of the remaining proximal phalanx to an adjacent intact phalanx, usually joining the long and ring fingers ; this is performed by interposing transversally, in the web space a bone peg (harvested from the injured metacarpal) supplemented by a transverse K-wire forming two bars of a "ladder". This operation avoids collapse of the ray and allows motion which is transmitted by the neighbouring intact MPJ. However, this operation deprives the intact finger of independent motion and it must be avoided for the second of 5th rays where collapse and subsequent clinodactyly could occur.

METHODS AND RESULTS

Prostheses and spacers

Beevers and Seedhom (1) have recently presented an extensive review of the available prostheses. Each has its particular advantages and drawbacks, which are beyond the scope of this paper. Suffice it to say that all fall short of the basic requirements and despite constant improvement, they still present significant problems of stability, durability, and mobility. They all are contraindicated in

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young patients. This lack of consistency explains why the Swanson spacer continues to enjoy popularity despite its numerous shortcomings. We have found it advantageous to use an anterior approach to the PIPJ. Sparing the insertion of the medial band of the extensor mechanism allows early motion and aggressive splinting in flexion. Spacers have, however, definite contra-indications and drawbacks. They require a good bone stock for insertion, which is frequently missing in complex trauma ; we have no experience with spacer insertion into a bone graft block. They have insufficient stability when subject to lateral stress as occurs in lateral pinch, which contraindicates their use for the index finger. If the patient is trained to support it ulnarly with a normal long finger, this drawback may be compensated. Unfortunately, durability and mobility also remain questionable. While we have found neither infection nor synovitis due to wear of the silastic or fracture of the implant to be problems, the primary concern is the limited *active range of motion (AROM)* decreasing with time, mainly at the PIPJ (12).

Bone resorption could even "bury" the prothesis, leading to stiffness in extension, a position worse than that obtained with a proper arthrodesis. This occurred in 3 of our 39 cases, with a mean AROM of 35° and an extension lag of 25° (at a mean follow-up of 28 months). At the MPJ level, results were more encouraging and in our trauma series of 18 cases, the mean AROM was 49° with an extension deficit of 20°, at a mean follow-up of 42 months.

Biologic joint reconstruction and transplantation

Because the complexity of the finger joints made use of prostheses difficult, biologic joint replacement has long made a reasonable alternative. These procedures fall into several categories : perichondral joint grafts and interpositioning of various materials, allografts, and autografts (half- or whole-joint transfers, vascularized or avascular).

A. *"Resurfacing" technique*

We only have limited experience with interposition of material. Our short series of perichondral grafts has been so disappointing over the long run (12), confirmed by other studies, that we abandoned this technique. This operation is applicable only to cases where damage is confined to the articular cartilage, in the presence of normal bone structure. The technique is well described (33), the graft is harvested on the anterior aspect of the sixth rib. A crucial point is to decrease the amount of pressure on the graft in order to avoid necrosis ; in some cases we have used external fixation for the first two weeks. Good initial AROM was obtained (12), but with a mean follow-up of 36 months our four cases had only 25° of AROM, while one was completely stiff in extension. Finally, we have no experience with compound cartilage-free grafts (32,35).

We have also used (in 3 cases) lyophilized pericardium (12), which gave good results in cases with limited cartilage loss.

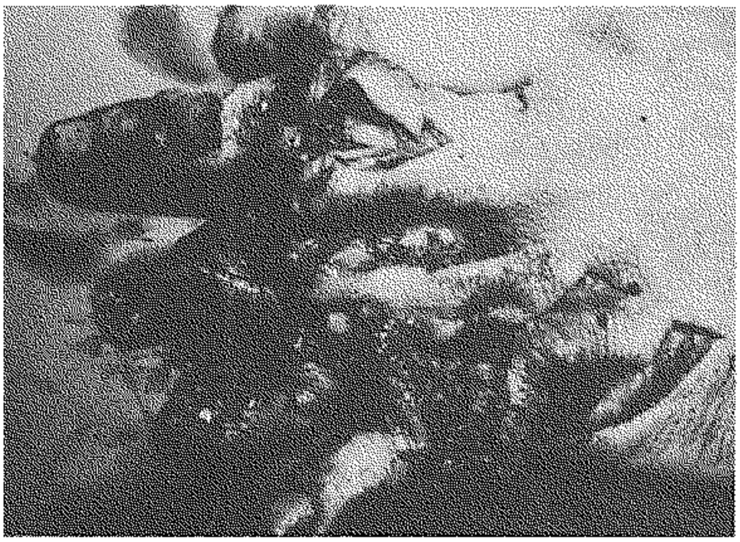
We have had some experience with the interposition of the volar plate (40), mainly in neglected comminuted fracture dislocations of the PIPJ, but also in two cases of replantation after amputation through the PIPJ (with 45° and 80° of AROM).

In the fracture-dislocation series, out of our 11 cases reviewed, one had recurrence while the others had a mean AROM of 60° (with a mean extension lag of 22°) at a mean follow up of 38 months.

B. *Non vascularized partial or whole joint transfer*

Joint transfer has long been used, with variable clinical results. Successful transplantation of any "graft" depends on rapid reestablishment of blood or synovial perfusion to allow survival and function. When bone and cartilage are transplanted, ischemic loss of synovium is responsible for poor production of synovial fluid, depriving the articular cartilage of its sole means of nutrition (33). The distribution of synovial fluid depends on joint movement, and prolonged immobilisation causes trophic changes in the articular cartilage (7). The role of denervation in degenerative changes in transplanted joints, although poorly documented, is probably unimportant (2).

Nonvascularized allografts and autografts (3, 4, 5, 45) have been largely unsuccessful, with a high



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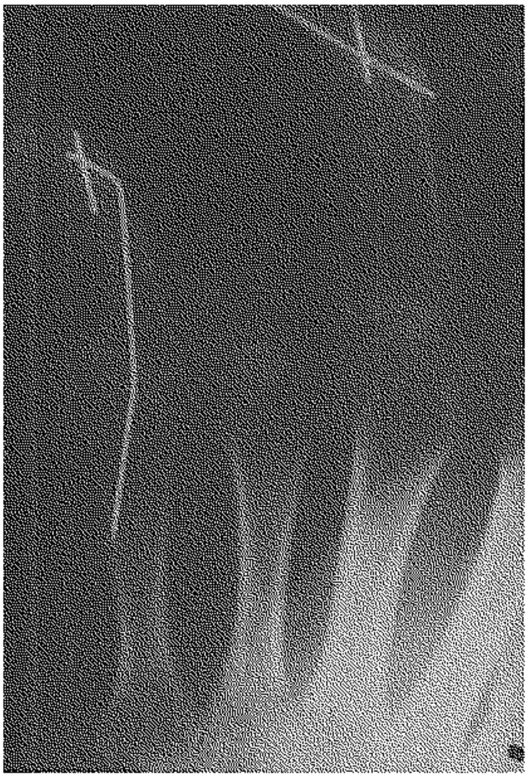

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Fig 1. a) Appearance of the left hand after mutilation in a 47 year-old man. b) amputation of the fourth digit with preservation of MP joint ; the joints of the fifth finger are entirely destroyed and temporarily stabilised by K-wires. c) translocation of the fifth finger to the fourth by Leviet intracarpal osteotomy and at same time interposition of the vascularized MP joint of the recipient finger. d), e) and f) functional and cosmetic result with a "four fingers hand". (G. Foucher, *Revue Chir. orthop.*, 1991, 77, 34-41. Masson, Paris, with permission).

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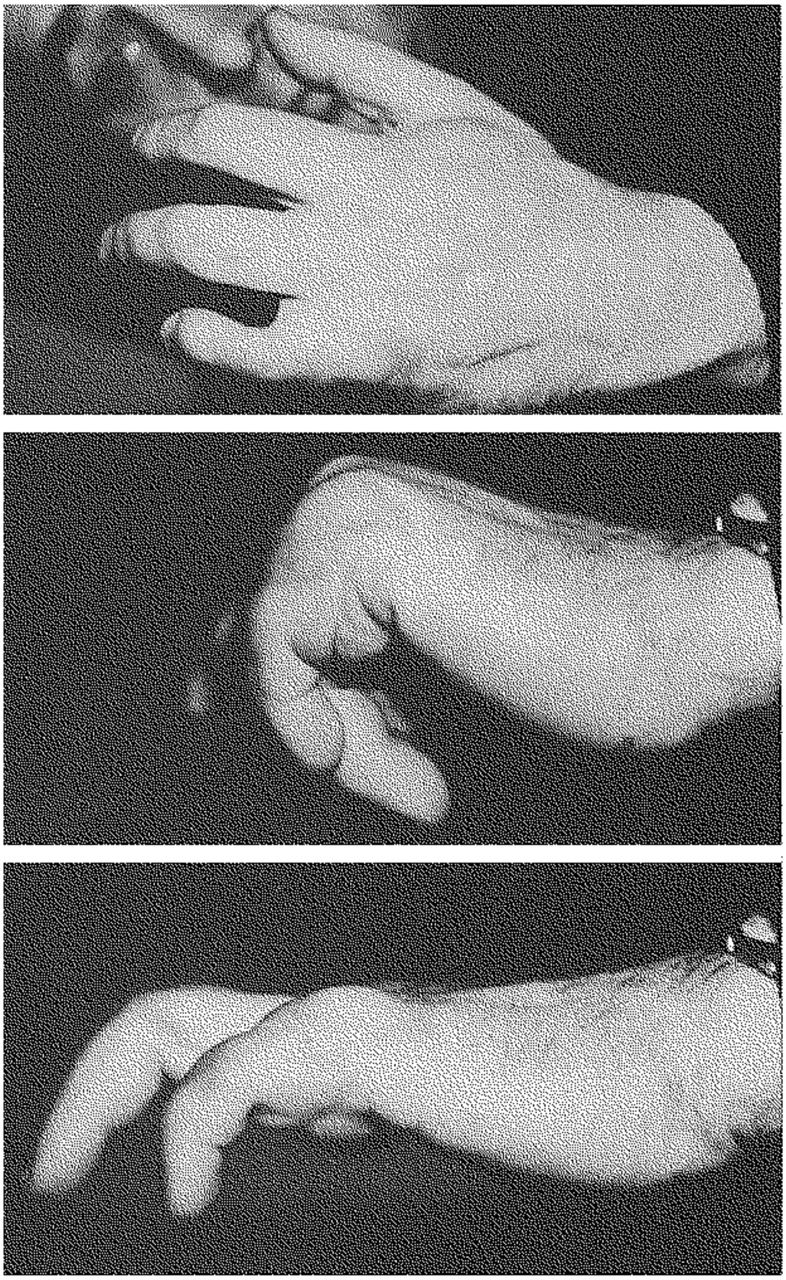

rate of failure. Occasionally, good mobility can be obtained, despite obvious and constant degenerative changes. Our limited clinical experience (12) in adults led to necrosis in two of four cases ; only one partial transfer performed acutely on a MPJ has given a satisfactory result (full range of motion).

C. *Vascularized joint transfer*

The technical feasibility of whole vascularized free-joint transfer was demonstrated experimentally, as early as 1966, and was associated with long term survival (34). Indeed, vascularized joint transfers (VJT) are histologically indistinguishable from normal joints with viable subchondral bone. Survival of the epiphyseal plate with growth has also been demonstrated experimentally and clinically. Since the first clinical island (5) and free VJT from the toe (38), few cases have been published (8, 10-15, 17, 26, 28, 38, 44, 48, 51).

The hand remains the ideal source to provide an anatomically matched joint. Three techniques can be used : heterodigital transfer (8, 10, 11, 26) from a "bank" finger (a finger otherwise sacrificed due to complex lesions), an island or free transfer (from a non-replantable digit) or a homo-digital DIPJ to PIPJ island transfer (13, 26).

a) Free or island heterodigital vascularized finger joint transfer (fig. 1)

The technique is similar regardless of the joint transferred (MPJ, PIPJ or DIPJ) or the recipient level (PIPJ or MPJ), but becomes more demanding when the donor finger is not sacrificed. First, the recipient site is prepared with skin debridement, extensor and intrinsic tendon preparation, and bone resection. The volar plate is thinned, taking care not to enter the flexor sheath. On the donorfinger, a dorsal skin flap is outlined ; two or three dorsal veins are dissected proximally on the same side as the nutrient artery. A long segment of extensor tendon is dissected to allow suture with overlapping. Following this, the digital artery is dissected free, keeping its surrounding fat to protect the venae commitantes. Distally, the artery is divided at the level of the future bone section. A double osteotomy subsequently isolates the joint while keeping the volar plate intact and preserving the vascular connections. The length of intercalated segment must be shorter than the actual recipient defect. When the compound transfer remains attached solely by its veins and artery, it is ready to be transferred to the recipient site, usually by a dorsal, subcutaneous route, in order to decrease dorsal scarring. Bone stabilisation can be obtained in many ways, but we favour bone penetration combined with interosseous wiring or K-wires in cases of discrepancy. When the fragment is very small (and in young patients) a single longitudinal K-wire is preferred to stabilize the transferred joint in extension, taking care to avoid any rotation. Then the flexor sheath is reattached to the donor volar plate to decrease the mechanical advantage, and the extensor tendon is secured by overlapping. At the PIPJ, the extensor is divided into two slips, one being secured to the central slip and the other to a lateral band. Finally, the treatment of the donor finger is determined by its potential function, and could involve arthrodesis, shortening, or ray amputation. Mobilisation usually begins at 4 to 6 weeks (at the time of K-wire removal in case of longitudinal insertion) with dynamic extension splinting to avoid weakening of the extensor suture. Splinting in flexion is postponed for 8 weeks. Our results have been quite rewarding ; in a series of 15 cases reviewed with a mean follow-up of 39 months, the mean AROM was 56° at PIPJ and 45° at MPJ level (11).

The technique is basically the same in the case of a free transfer from a non replantable finger using either the DIP (10) or the PIP. However microsurgical repair of the artery and veins is mandatory. Our two cases have recovered 65° and 80° of AROM.

b) Homodigital DIPJ to PIPJ island transfer (11, 13, 26) (Fig. 2)

Littler has stressed that the DIPJ only contributes 15% of the arc of finger joint mobility, compared to 80% for the PIPJ. Thus, a DIP to PIP transfer provides a two-joint finger, with proximal mobility and finger shortening, preventing locking of the finger in a fist position.

The technique differs only slightly from the heterodigital island transfer, but due to conser-

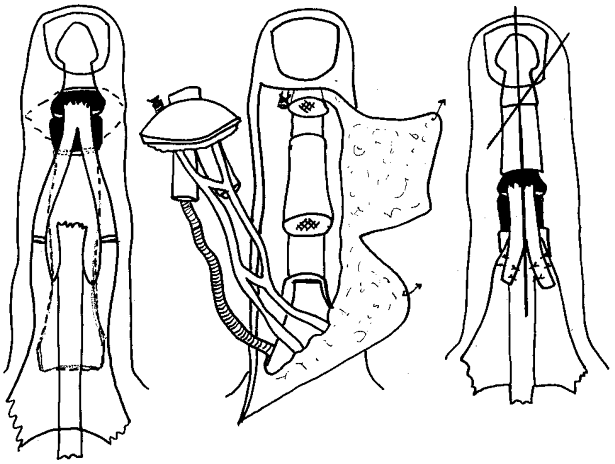

Fig. 2. — DIP to PIP homodigital compound island joint transfer.
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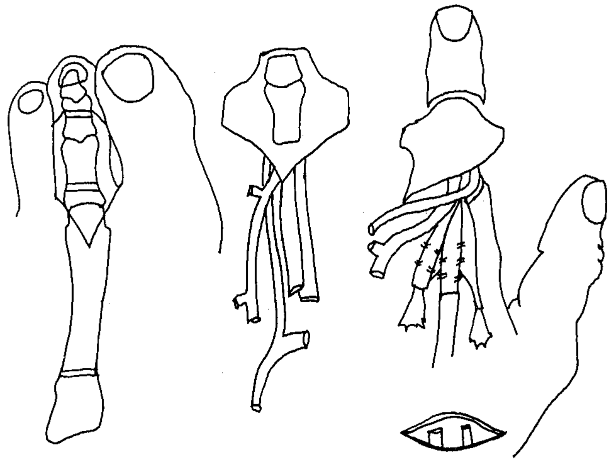

Fig. 3. — Vascularized compound joint transfer from the second toe based on the vessels of either the first or second spaces.
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vation of the finger a more precise technique is mandatory. A satisfactory DIPJ with free gliding of the flexor tendon and two patent digital arteries are necessary prerequisites. A midlateral incision on the side of the sacrificed artery is extended to the web. Three transverse incisions are used, two to isolate a dorsal skin flap at the DIPJ level, and one at the PIPJ level to insert the transfer. This creates a dorsal flap at the middle phalanx which is gently lifted to dissect two or more dorsal veins for the transfer. It also allows preparation of the extensor mechanism, which is severed close to the PIPJ. The DIPJ is then harvested via two transverse osteotomies 6 to 8 mm apart, avoiding the nail matrix distally and the insertion of the volar plate proximally. The collateral artery subsequently is severed at the level of the distal bone section and the compound island is transferred to the PIPJ level as described above. A longitudinal K-wire allows fixation of the joint, and the distal arthrodesis is secured by another oblique wire in addition to profondus flexor tendon reinsertion (a detail particularly relevant for the fifth finger). Finally, the vessels are folded and buried in the web prior to skin closure.

We have reviewed 7 such cases with a mean follow-up of 18 months. We had two complications : one technical failure and one minor nail dystrophy. The mean AROM was 52°.

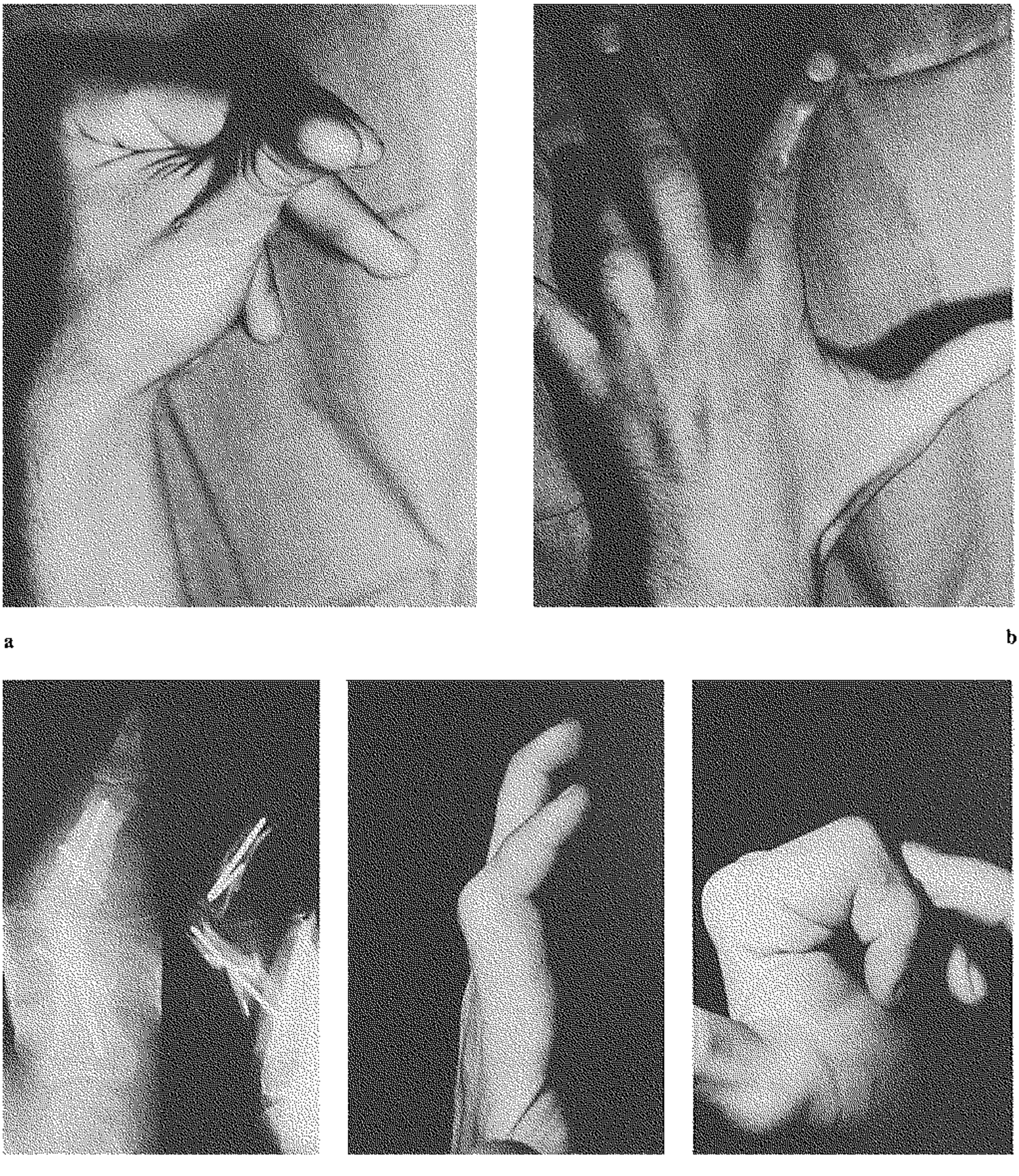
c) Free vascularized toe joint transfer (Fig. 3, 4)

Two types of joints are available : the PIPJ and the metatarsophalangeal joint (MTPJ) of the second and/or third toe ; two techniques may be used — simple or double en bloc transfer.

We have extensively described the technique elsewhere (8, 9, 16, 21) ; here, we will only summarise a few relevant technical points.

The vascularization pattern of the second toe has been well characterised (27, 28, 38, 39) but few studies have been devoted to the vascular pattern of the joints (38, 50, 51). The blood supply of the MTPJ depends on the articular branch of the first dorsal metatarsal artery most commonly arising at the distal third of the metatarsal bone (38) while small branches also originate from an artery (often overlooked in the literature), the second plantar metatarsal artery (8, 16, 18). This vessel has been found to be constant, reliable, and passes in close proximity to the plantar plate. The PIPJ is vascularized by branches coming from the proper plantar digital arteries (50, 51).

Several techniques are possible : (1) single toe PIPJ transfer for MPJ and PIPJ finger recons-



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c d e

Fig. 4. — a and b) destruction of all PIP joints in a young boy (except PIP of the fifth finger). c) X-ray appearance 2 months after the transfer of the PIP of the second toe. d) and e) extension and flexion of the reconstructed index two years after the transfer.
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truction ; (2) single MTPJ transfer for MPJ or PIPJ reconstruction ; (3) double transfer of PIPJ for MPJ reconstruction ; (4) double transfer of PIPJ and MTPJ for MPJ reconstruction, and (5) the "twisted toeflap" technique to add a joint in a "wrap around" thumb reconstruction.

The dissection is quite similar in all these transfers, and we continue to favor the technique we described originally (15-17) using the second toe. We use a one team approach, beginning with donor site dissection, under general anesthesia and core temperature monitoring. A cutaneous flap is drawn distal to the DIPJ, and is prolonged proximally by a long tail on the dorsum of the foot, joining the straight incision centered on the first space.

This unique dorsal approach (8, 16, 18) allows for successive dissection of the vein network and the dorsalis pedis artery and the dorsal artery of the first space. If the second toe is sacrificed, a proximal metatarsal osteotomy is performed early. This osteotomy has two advantages : (1) it provides wide exposure to the plantar arterial system of the first and second spaces after lifting the metatarsal shaft and (2), it facilitates closure of the donor site. We attempt to harvest as many arteries as possible, our clinical series of 207 toe transfers having proved that no vascular compromise occurred when more than one artery was feeding the transfer (21, 23, 24). These remain in continuity with the dorsalis pedis artery and the plantar arch, allowing interpositioning the segment as a "T" graft with two end-to-end sutures (8) either in the palmar arcade or the radial artery at the snuff box. The toe is then divided distally through the DIPJ. The skin is split on the medial line of the plantar aspect and two lateral flaps are reflected back to the vascular bundle.

The flexor sheath is then opened longitudinally to remove the flexor mechanism, with care being taken to avoid injuring the retrotendinous vessels and the vascular supply of the plantar plate. An osteotomy is performed to bring the first phalanx to the length required. A bone peg can be harvested from the discarded metatarsal for bone stabilisation either at the donor or recipient sites. When the compound transfer remains pedicled only by its arterie(s) and vein(s), the tourniquet is released. Topical vasodilator (Lidocaine 5 percent) is applied to the artery, and the foot is wrapped with warm wet drapes. Preparation of the hand frequently requires extensive excision of scarred dorsal tissue. The flexor sheath is emptied and the remaining volar plate is thinned. The bone ends and the extensor mechanism are prepared. A separate approach is used for recipient vessels ; if the radial artery is selected, a horizontal incision is performed at the snuff box. If the palmar arteries are used, two short incisions, one palmar and one dorsal (transverse for the vein) are necessary. Undermining of the supple dorsal skin avoids conspicuous scar on the "social" aspect of the hand. Precise measurement of length of bone and pedicles is then carried out, prior to separating the joint from the donor site. The compound joint is then transferred to its recipient site and the bone secured as previously discussed. The remnant of the flexor sheath of the toe is sutured to the rim of the recipient sheath to prevent bowstringing of the flexor apparatus. The extensor mechanism is sutured with overlapping, with the joint in full extension, the extensor hallucis longus to the central slip, and the extensor brevis to the intrinsic tendon. The bundle is then passed through the usually ample subcutaneous tunnel, avoiding any twisting, and the skin flap is carefully trimmed, inserted, and sutured (Fig. 3, 4). The vessels are then sutured end-to-side or end-to-end (T-shaped) for the artery and end-to-end for the single vein. The tourniquet is then removed and the donor site is closed after hemostasis. Intermetatarsal ligament reconstruction is performed and the skin is closed after placement of drainage tubes. Our preference for second ray amputation is based on problems encountered following donor site grafting (non-union and delayed ambulation). On the other hand, a report by a foot surgeon based on 20 cases of toe amputation (Moyen 1982, unpublished) demonstrated that when the metatarsal was left in place, there was a consistent tendency to hallux valgus deformity. This problem was not seen after ray amputation, except when the angle between the first and second metatarsals was greater than 20°. In such cases, reconstruction of the second toe should be considered.

Only minor changes in this technique are necessary according to the type of transfer. The PIPJ can be used for thumb reconstruction in a technique that we have called "Twisted Two Toes" (TTT) (8, 15, 25, 37, 49) : skin and nail complex are taken from the ipsilateral big toe based on the first dorsal (and/or plantar) metatarsal artery en bloc with a piece of vascularized bone, longitudinally harvested from the distal phalanx of the great toe. This Longitudinal Bone Harvesting (LBH technique (22)), which we use in all "custom made" thumb reconstructions (including bone) has several goals : it avoids bone resorption, provides good fixation for the pulp and nail support, allows curvature of the nail to decrease its visual projection ("illusion" technique (22)), and does not shorten the great toe. The PIP joint with its extensor and flexor tendons is raised with the adjacent skeleton (if necessary the MTPJ can be included and tilted 45° palmarly on the thumb metacarpal to avoid a "Z" deformity. They are fed by the second plantar metatarsal artery. Both arteries are harvested in continuity with the dorsalis pedis artery, which is used for a T-shaped intercalated graft. The joint is buried into the great toe flap and the second phalanx is attached to the "LBH" by a K-wire. In this way, a two phalanx "custom-made" thumb is constructed, which may be transferred to the thumb stump in the standard manner. Either a graft or an ulnar-based triangular flap, tailored from the stump, is used to cover the ulnar side of the filleted big toe skin. At the donor site, the proximal part of the second metatarsal bone is removed, the intermetatarsal ligament repaired, and the filleted second toe skin wrapped around the skeleton of the big toe with a Z-plasty. This "TTT" has several advantages over the classic "wrap around" (41) in that it provides a vascularized skeleton which avoids resorption), two phalanges (analogous to the normal thumb), some mobility (a PIPJ plus an MTPJ when necessary, with extensor and flexor mechanism), firm support for the pulp and nail, and a growth plate in children. In a series of 7 cases reviewed with a mean follow-up of 5.3 years, the mean AROM was 32°.

Other double transfers are based on the same principle of separate use of the vascular bundles of the first and second spaces. It is thus possible to harvest two PIPJ's on the second and third toes and to transfer them with only one arterial anastomosis (8) (Fig. 5). It is also possible to harvest two separate joints from the second toe, the PIPJ and the MTPJ (Fig. 6), for reconstruction

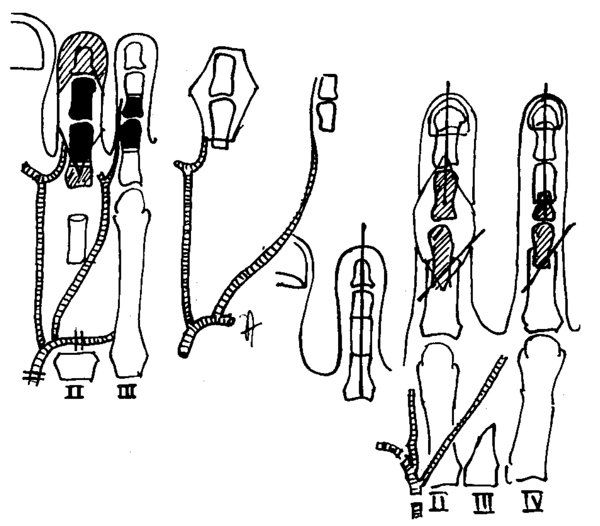

Fig. 5. — Double vascularized joint transfer from the second and third toes, based on two separate vascular bundles from the first and second intermetatarsal spaces.
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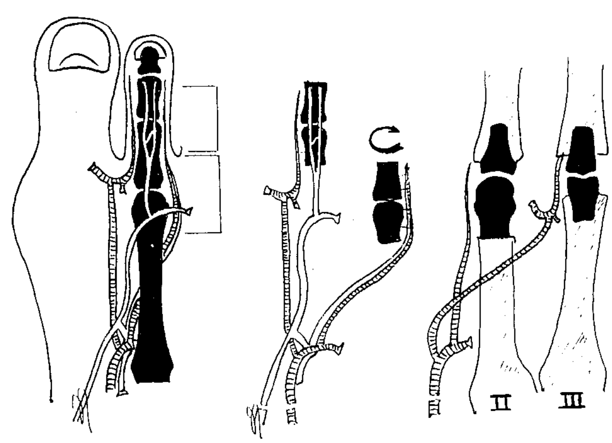

Fig. 6. — Double vascularized joint transfer from the second toe, based on two separate vascular bundles from the first and the second metatarsal spaces.
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of two MP finger joints. When used, the MTPJ must be rotated 180° to provide a useful range of motion.

The functional results with free VJT from the toes have been quite disappointing in adults. In our published series of 25 patients (17), we noted several complications : two graft failures, one successful reexploration for arterial thrombosis, one pin tract infection, and one small skin slough resulting in secondary scarring. With a mean follow-up of 66 months (14 months to 20 years) our MPJ reconstructions had a mean AROM of 35° (20° to 50°) with a mean extension lag of 45°, while the PIPJ had AROM of 33° (ranging from 0° to 75°) with an average of 39° extension lag. The only good news concerns the absence of radiologic deterioration and the persistence of cartilage growth plates in children. We have more recently reviewed separately 6 cases of PIPJ reconstruction in children, where the result was more rewarding, with a mean AROM of 56° and a mean extension lag of 26°.

DISCUSSION

It is impossible to thoroughly discuss the entire literature on this topic, and it would be wrong to compare techniques which cannot be compared due to different indications. The decision itself as to indications is worth mentioning. The indication depends upon factors related to the patient and to the local problem. The age, sex, associated pathology, employment and leisure activities, motivation, and desire should be considered. Locally, many factors are of relevance. The perfusion and general condition of the finger could be limiting factors for any type of reconstruction. The condition of the flexor tendon is a cornerstone for decision. Extensor and dorsal skin conditions are more manageable through compound vascularized transfer. A major factor remains the size of the tissue loss. In cartilage surface losses, there may be a place for resurfacing procedures, even if our results have been frustrating. In their review of 36 perichondral arthoplasties, Seradge *et al.* (46) found that infection and age over forty were contra-indications. We have no experience with composite free grafts including bone, but some authors have reported interesting results in children (29, 32).

An excellent technique for partial cartilage loss after PIPJ fracture dislocation with comminuted volar fragment, even when seen late, is volar interposition (40). Our results are close to those of the original series (40).

Limited losses with good quality extensor tendon and skin are the classical indications, in adults, for prostheses or spacers. The high rate of mechanical failure of prostheses remains a major concern, but osseointegration (6) may hold promise for the future. Swanson spacers are currently the most frequently used method despite many drawbacks in post-traumatic cases (31, 43, 47). These include infection, sinking, breakage (36), silicone synovitis (including malignant lymphoma) (42), lateral instability, and limited AROM.

In compound losses, free vascularized joint transfer remains the best option. Our best results, approximating a useful range of motion (30) were provided by island or free finger joint transfer. DIPJ to PIPJ transfer is limited to very small losses ; this technique has replaced, for us, use of spacers when a good DIPJ is available and the two collateral arteries are patent. The technique is demanding but 56° of proximal mobility of a shortened finger avoids the finger being held in a near-fist position. In more extensive compound losses, the two alternatives are VJT from a "finger bank" (an otherwise discarded finger) or from the toe. The former gives superior results and is favored when possible in adults. Globally the AROM for the reconstructed MPJ was 45° and 42° for the PIPJ. The latter has several theoretical advantages : a useful range of motion in an acceptable arc can be obtained with good lateral stability, providing strong opposition to the thumb in pinch. Furthermore our 20 years follow-up of our first case (14) has demonstrated clinical durability, corroborating experimental data. Finally, the two main advantages are the possibility of growth in young patients and the possibility of a compound transfer, providing not only joint, but also bone stock, extensor mechanism and skin, in a one-stage procedure. However it also has many shortcomings : it is a long and demanding operation lasting an average of 3.5 hours, it must be performed under general anesthesia with lengthy hospitalisation required (average 5.3 days), and the risk of failure has to be discussed with the patient, as in all microsurgical procedures. We are increasingly reluctant to perform such transfers in adults due to excessive limitation of range of motion, with an associated lack of extension (12, 14, 15, 18, 28, 51). This was also the case in the Tsai' series of 29 patients reviewed with an average follow-up of 1.9 years (48) : the complication rate was 48% ; no motion was recorded in 28% and in successful cases the TAM was 46°.

We currently restrict the indications to adults with multiple joint involvement (mainly of the radial fingers, where lateral stability is more important than amplitude) and to children, where the results is better and the technique allows growth.

In conclusion all techniques of joint reconstruction fall short of the ideal, especially at the PIPJ level. Prostheses need to be improved and have to survive the test of time. Vascularized joint transfer is an interesting option, primarily in complex situations, even if these techniques result in a very limited range of motion. Here, again, the aphorism of Bunnell is worth keeping in mind : "When there is nothing, a little is a lot" especially when this "little" is painless and stable in space and time. This technique provides the unique advantage of a compound transfer of skin, bone, joint, tendons, and growth plate. Until vascularized allografts become clinically available, this is a worthwhile technique in well selected complex injuries.

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