Arch Orthop Trauma Surg (1990) 109:295–303

Archives of Orthopaedic and Trauma Surgery

Biological internal fixation of fractures

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Summary. Trauma centers treat more and more patients who have sustained multiple injuries during high energy accidents. The techniques of internal fixation of such fractures may be dictated by the concomitant soft tissue trauma, rather than by the bony injury. Three stages of soft tissue injuries are recognised: Stage I delineates compromised soft tissues which may be treated with standard techniques of internal fixation, provided that further devialization by surgery is avoided. Stage II implies partial, non-circumferential destruction of soft tissues, requiring alternative techniques of internal fixation to prevent (mainly septic) complications. In stage III, the soft tissues about the fracture site are destroyed and need early, specific soft tissue reconstruction. Indirect reduction without further devascularization of bone, aiming at perfect alignment rather than anatomical reduction of extraarticular fractures, optimal rather than maximal internal fixation as well as the inclusion of soft tissue reconstructive procedures into the armamentarium of the orthopaedic surgeon, require an intellectual and technical reorientation but can be shown to improve the results of the treatment of fractures with concomitant soft tissue injury.

Internal fixation has become increasingly important in the treatment of fractures because its advantages have been shown to outweigh the undeniable potential of complications in a great variety of fracture types. The tibial fracture is an example of the potential of internal fixation to allow much earlier resumption of work, to reduce residual disability [1] and thereby to reduce significantly the overall cost of treatment [22]. In the treatment of injuries of the long bones of the multiply injured patient, immediate internal fixation is not only an elegant means of stabilizing fractures and aiding nursing, it substantially reduces pulmonary complications and saves lives [2, 4].

When internal fixation of fractures was first promoted by the AO group, the techniques aimed at anatomical reduction and stable fixation of all fragments [18]. Primary healing of bone was found to be possible if the fracture gaps were closed and if optimal stability was achieved [27]. Although the originators thought from the beginning that soft-tissue handling is of paramount importance, the drawings of the *Manual of Internal Fixation* [18], which neglected all soft tissues, led readers to believe that internal fixation of fractures was purely a matter of surgery on the bone. The new AO classification of fractures [19], which does not address the problem of associated soft-tissue injuries, may reinforce this impression.

Clinical experience revealed that especially plating techniques are associated with substantial risks in high-energy injuries of bones with little soft-tissue coverage such as the tibia [29]. The worrisome incidence of postoperative wound complications and infections [15] led to a certain reluctance to use standard techniques of internal fixation for either difficult or open fractures, and it was recognized that a higher success rate of internal fixation was mandatory in problematic fractures.

At least three parallel evolutions have helped to improve the treatment results:

- The multiple improvements in closed functional bracing of fractures suggested that at least a fair proportion of extra-articular fractures can very successfully be managed without the risks of rigid stabilization but with the benefit of immediate functional care [25, 26]. This contribution rendered some forms of temporarily advocated operative treatment, such as primary plating of humeral shaft fractures, virtually unnecessary [26].

- For operative cases, the routine administration of effective prophylactic antibiotics helped to reduce the infection rate to an acceptable level even for open fractures [21].

- Less invasive modes of surgical fixation such as locked intramedullary nailing [11, 14, 16] or the wider use of the external fixator [5] gave the orthopaedic surgeon the possibility of treating high-risk fractures with much less soft-tissue dissection and additional devascularization by virtue of a different fixation technique and thereby of exploiting the advantages of different modes of fixation for optimal fracture healing [20].

This progress, however, has not solved the dilemma of difficult, intra-articular fractures, of epi-metaphyseal fractures or of multi-level injuries involving joints, and it

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has not conceptually addressed the possible necessity of soft-tissue reconstruction.

In an attempt to reduce the disadvantages of internal fixation to a minimum but to retain all its advantages, the methods and techniques of internal fixation have been gradually and systematically modified in the past decade. This has resulted in a concept of fracture treatment which strives to obtain optimal rather than maximal stability with a minimum of soft-tissue dissection and implants, a concept which therefore is reoriented from a purely mechanical towards a biological approach to internal fixation. The improvement over previous treatment strategies has been documented for certain fracture types in our own material [15] and is daily reflected by the virtual disappearance of septic fracture complications on the ward. It is the purpose of this paper to present this concept of a more biologically oriented technique of internal fixation. This technique is intellectually and technically demanding and requires breaking certain taboos. Our experience, however, suggests that, if used correctly, it is a "bio-logical" form of management which yields clearly superior results to those obtained with standard techniques especially in fractures with associated soft-tissue trauma.

The concept

The technique of internal fixation to be used is dictated by the soft-tissue conditions about the fracture and the additional devascularization imposed by the type of internal fixation to be used. Anatomical reduction of articular fragments is considered mandatory, but the reduction and internal fixation technique must preserve their vascularity. Anatomical reduction of extra-articular fragments is not considered mandatory. Reduction restores the length and alignment in all three planes. Internal fixation must avoid additional devascularization and stabilize the fracture site so as to allow functional aftercare. Meta-diaphyseal fractures are allowed to heal in optimal alignment as if the fracture were treated "conservatively". Indeed, biological internal fixation represents conservative surgical management of a fracture.

Three stages of soft-tissue involvement are recognized and imply a progressively more elaborate surgical technique; these stages continuously blend into each other and overlap according to the judgement of the treating orthopaedist:

1. The *soft tissues* including the periosteum are *compromised* but can be managed with classic *standard techniques* of stable *internal fixation,* provided the soft tissues are dissected with maximum care and strict avoidance of any further devascularization of the fracture site.

2. The *soft tissues* are *partially destroyed* so that the additional trauma of a standard surgical procedure would devitalize the fracture site and invite wound problems and infection. The accepted *standard techniques of internal fixation* are *not applicable* and need to be modified. Careful preoperative planning and techniques of indirect reduction [17] and minimal internal fixation are of paramount importance.

3. The *soft tissue* envelopment of the fracture site is *destroyed* and needs *reconstruction* in addition to the treatment of the bony lesion. The soft tissue injury may be incurred in an open or in a closed fracture with extensive contusion, degloving etc. Internal fixation may be classic, but modified techniques are used more frequently. Reconstruction of the extremity often requires staged procedures.

The practice

Treatment of stage I lesions

Fractures of the shafts of those long bones with a quite favourable soft-tissue envelopment which are severely displaced fall into this category (Fig. 1). Fractures of the forearm or of the femur are typical examples. If the fracture is open, the skin is cleaned with soap, brushes are only used on dirty, superficial excoriations and not over the lesion. The margins of the skin lesion are excised. Debridement is carried out with the scalpel, and irrigation is used. Meticulous surgical debridement usually with optic magnification (loops) is considered to be more important than irrigation. The use of brushes is strictly avoided on muscle and bone. Debridement is complete when the wound is comparable with a surgical wound. The skin lesion is included in the surgical approach. If an additional approach is necessary, it is selected so as to allow one to cover the fracture site with viable soft tissue (Fig. 1). Full visualisation of the fracture fragments is avoided in order to preserve the remaining blood supply; reduction is by indirect techniques, often by fixing a plate to one fragment and reducing the fracture to the plate. If the soft tissues are meticulously preserved and the surgeon resists the temptation to expose the entire fracture, bone grafting is very often unnecessary. Primary bone grafting is contraindicated if soft tissue dissection is necessary to allow placement of the graft.

The transition of a stage I into a stage II lesion is difficult and somewhat arbitrary. Lesions which might be amenable to standard techniques of internal fixation can be transformed into stage II or stage III lesions by inappropriate use of devitalizing incisions and additional soft tissue stripping (Fig. 2). Comminuted fractures in the epi-metaphyseal region of the knee and particularly of the proximal tibia should always be considered as stage II lesions. The use of bilateral plates has specific indications, such as the distal humerus, but should be avoided in regions with less favourable biology, such as the contused knee area.

Treatment of stage II lesions

Partially destroyed soft tissues or compromised vascularity of an articular segment may require modifications in the practice of internal fixation (Fig. 3). A modification is always necessary when a standard procedure would imply additional soft-tissue compromise at the fracture

Fig. 1. **a** Open fracture of the forearm; the type IIIA [9] skin lesion is over the ulna. **b** Without any additional devascularization, the fracture is treated as a stage I lesion with a standard internal fixation technique, without bone grafting. **c, d** The wound is closed over the ulna because the soft tissue envelopment is critical at this site; the skin is not closed over the radius as this bone is covered with vital musculature. **e** Uneventful healing was associated with full functional recovery

site, e.g. compromise of the partial soft-tissue envelopment which serves as venous and lymphatic drainage after a very short period of recovery. Epi-metaphyseal fractures of the proximal tibia are typical examples. Bilateral incisions in situations such as that depicted in Fig. 4 should be completely avoided. Combinations of different fixation techniques may be necessary. The joint may need careful reconstruction with a minimum of possible transcutaneously placed screws. The epi-metaphyseal zone may need bridging with a plate to assure alignment. The medial side of the tibia which lies directly under the skin must not be exposed in such a situation. As there is no medial buttress against which the lateral plate can be put under tension, it may have to be provided by a transcutaneously applied external fixator. In such a fracture, healing of the anatomically reduced and fully stabilized articular segment could be by primary bone healing, but the meta-diaphyseal fracture zone will heal according to the phenomena known from "conservative" treatment.

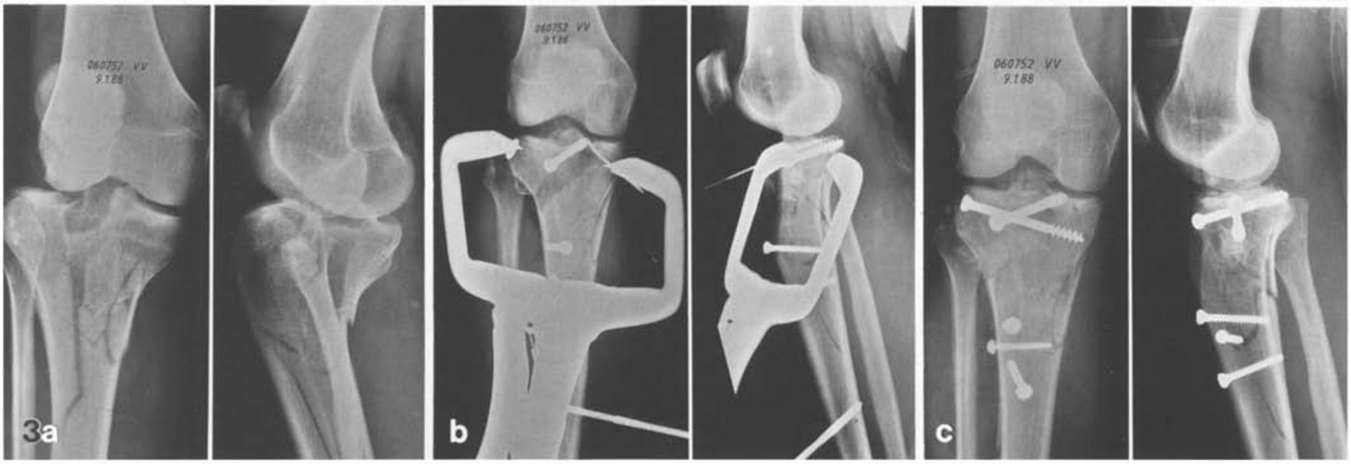

Fig. 2a–c. The soft-tissue injury in this bicondylar fracture (**a**) was severely underestimated during the initial internal fixation. A Y-shaped skin incision had been used, and the medial and lateral soft tissues had been stripped to apply two plates (**b**). Infection of the devitalized fragments led to septic arthritis, implant removal and debridement and ultimately to fusion of the knee (**c**). Such fractures are usually stage II lesions and should be stabilized with much less devascularizing internal fixation techniques

Fig. 3. a Bicondylar burst fracture of the proximal tibia. **b** A combination of indirect (femoral distractor) and atraumatic direct (transcutaneous vice grip forceps) reduction techniques allow anatomical reduction of the joint fracture without additional soft-tissue injury. **c** Internal fixation by screws alone; the sutures reinserting the torn anterior cruciate ligament are tightened around a screw head. **d** Uneventful, rapid healing

The combination of unilateral external fixator and contralateral plate has proven extremely useful in such situations, with the following advantages:

- It allows secondary corrections of malalignment
- It provides stability but may allow micromotion and promote healing [8]
- It temporarily replaces the contralateral cortex [17].

Stage II lesions of the shaft should no longer be treated like intra-articular fractures. The anatomical reduction of the shaft is unnecessary and can often only be achieved if significant devascularisation of the fragments is accepted. If shaft fractures are plated (Fig. 5), the plate is adapted to either the proximal or the distal main fragment, the fracture zone is then indirectly reduced either with the distractor or the extension table, optimal alignment is ascertained, intermediate fragments are approximately reduced without visualizing the far cortex, and the plate is fixed to the proximal fragment using the tensioning device. Screws are only placed where necessary; the filling of each screwhole is unnecessary. The fixation must be balanced: if one major fragment can only be held with 2 or 3 crews, approximately the same number of screws will be sufficient on the other main fragment (Fig. 6), and there is absolutely no rationale to fix an articular fragment with 1 or 2 screws and then use a long plate with a large number of screws to fix the shaft to the plate.

The technique of indirect open reduction using the femoral distractor, no medial exposure, no bone graft and the tensioner has been compared with a standard

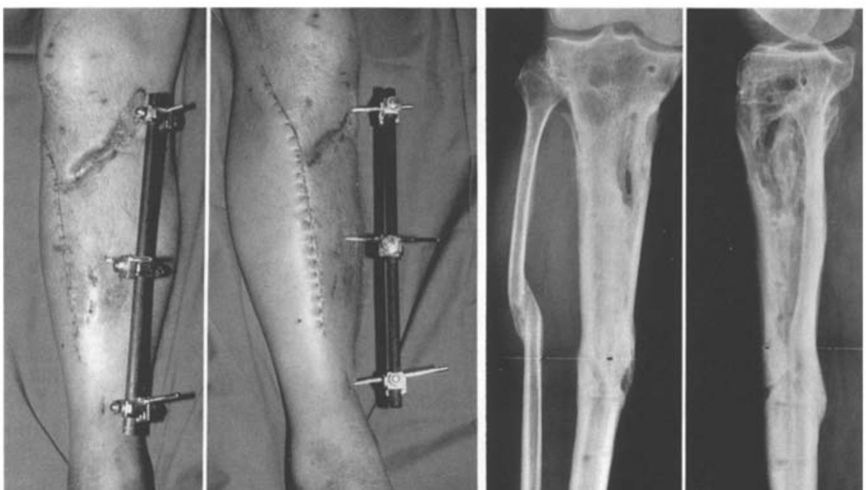

Fig. 4. a Severely comminuted fracture of the tibia. **b** The intra-articular component was stabilized with a single screw; axial alignment and sufficient stability for functional aftercare were assured by a lateral bridging plate and a transcutaneously applied external fixator. **c** The fixator could be removed after 6 weeks. **d** Good joint reconstruction, anatomical alignment after undisturbed healing of the fracture

anatomical reduction technique in two consecutive series of subtrochanteric fractures of comparable severity [15]. Although the second group benefited from routine antibiotic prophylaxis, the summary of the data (Tables 1 and 2) shows clearly the superiority of the "bio-logical" approach.

The preservation of the blood supply may be crucial in articular fractures. This has especially been studied in proximal fractures of the humerus; those with three or four displaced segments (head, shaft, greater and lesser tuberosity) have a substantial risk of avascular necrosis of the humeral head. Here, minimal internal fixation led to a 10% incidence of avascular necrosis but fixation with a plate, to a necrosis rate of 30% [28]. In a series of 8 four-part fractures treated with closed reduction and percutaneous pin fixation, Jaberg reported six excellent, one satisfactory and one poor result and a success rate of 80% in 16 three- and four-part fractures [13]. It seems clear that the ascending branch of the anterior circumflex artery is by far the most important nutrient artery

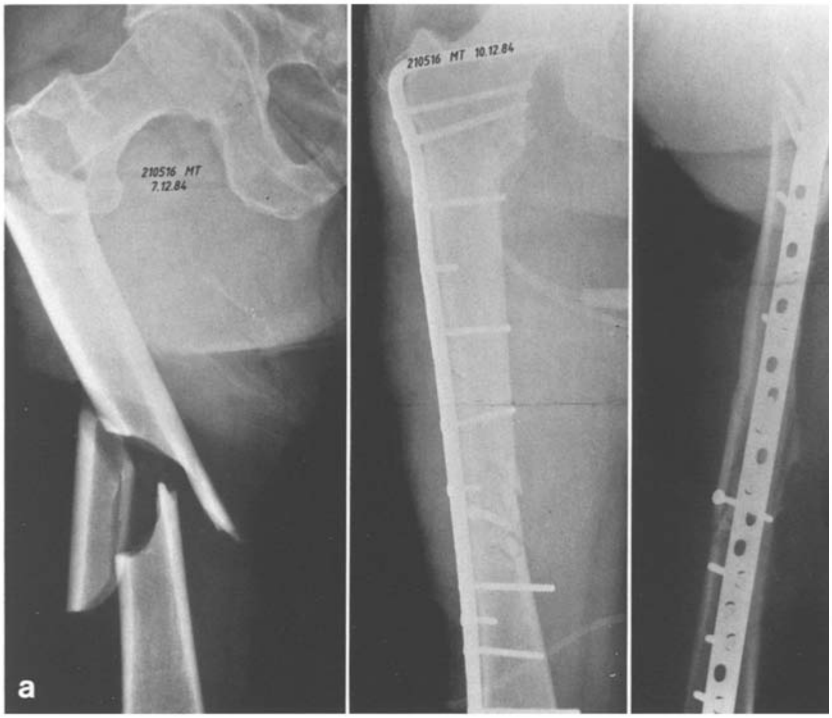

Fig. 5a, b. Multi-level fracture of the femur. A condylar plate is inserted into the proximal fragment, reduction is obtained indirectly by use of the femoral distractor, without visualizing the medial cortex. Fixation with 3–4 screws in each of the fragments after tensioning the plate (**a**). Uneventful healing without bone grafting (**b**)

Table 1. Subtrochanteric fractures ($n = 47$) (from [15])

Methods of treatment	Group A ($n = 24$)	Group B ($n = 23$)
Dissection medial cortex	54%	0%
Bone graft	41%	0%
Use of tensioner	37%	95%
Prophylactic antibiotics	13%	87%
Operative time (h)	2.2	2.1

Group A, indirect open reduction; group B, standard anatomical reduction

Table 2. Subtrochanteric fractures ($n = 47$) (from [15])

Treatment results	Group A ($n = 24$)	Group B ($n = 23$)
Follow-up (months)	36	21
Non-union	17%	0%
Delayed union (> 6 months)	17%	0%
Time to healing (months)	5.4	4.2
Time to full weight-bearing (months)	5.5	3.5
Infection rate	21%	0%

Group A, indirect open reduction; group B, standard anatomical reduction

[6], and if it can be preserved, survival of the humeral head is ascertained. Closed reduction and percutaneous pinning are unlikely to injure this vessel as opposed to plates in the region of the greater tuberosity [18]. Extreme caution with soft-tissue dissection and precise knowledge of the vascular anatomy dictate the use of minimal internal fixation techniques in this topographical region.

Treatment of stage III lesions

If the soft tissue surrounding the fracture site is destroyed, surgical debridement becomes the key to success. It is imperative that debridement be carried out without considering the reconstructive needs; if reconstruction is constantly considered during debridement, the latter is likely to be incomplete. Only after debridement will it become necessary to determine the exact modalities of soft-tissue reconstruction. Revascularization and replantation have a formidable place in the treatment of certain injuries to the upper extremity. The role of replantation and revascularization of the lower extremity is much less well established. The possibility to revascularize or replant extremities has unquestionnably often led to triumph of technique over reason and has tended to let us forget that amputation has a very definite place especially in grade IIIC [9] open fractures of the lower extremity [10].

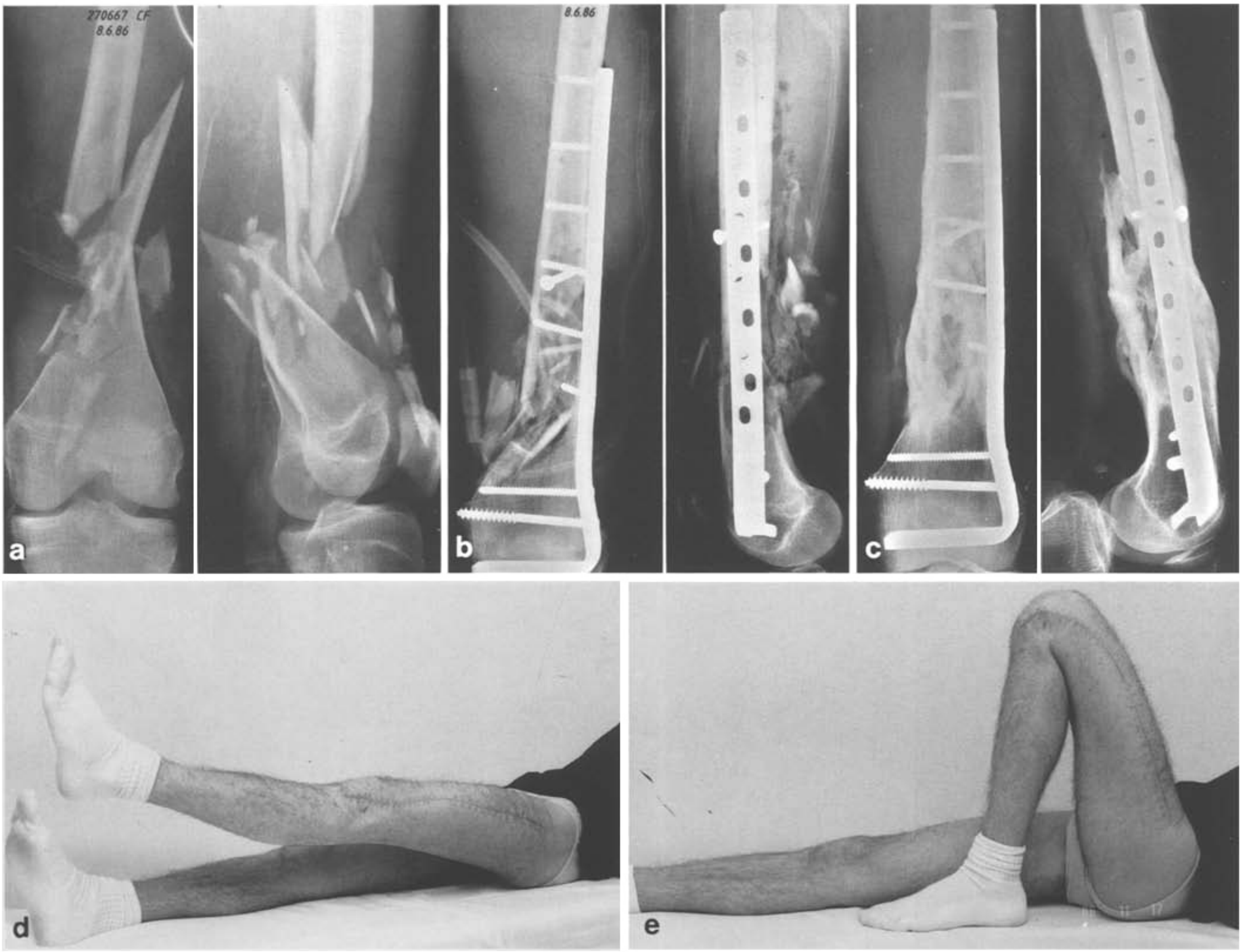

Fig. 6. a Comminuted open fracture of the distal femur. **b** Insertion and fixation of the plate to the distal fragment, reduction to the shaft using compression, without visualizing the medial cortex and without using bone graft. **c** Uneventful healing as in a "conservatively" treated fracture. **d, e** Full recovery of function

If, however, the neurovascular status of the extremity can be restored and a substantial soft-tissue deficit appears to invite infection with secondary vascular complications and osteomyelitis, soft-tissue reconstruction either with local or with free, usually muscular flaps becomes mandatory. Thorough debridement and quick skeletal stabilization are often the first steps. If the treatment can be accomplished in a one-stage procedure, conventional techniques of internal fixation may be used and the implants and fracture site covered with viable tissue, preferably muscle. A preliminary stabilization is more often necessary. This is usually obtained with an external fixator which is placed so that a locoregional or pedicled flap could be moved into the defect and/or a vascular anastomosis could be easily realized. If an uncompromised donor site for an ideal muscular flap is available, the optimal treatment is a one-stage reconstruction (Fig. 7). This is often the case in injuries of the proximal upper limb, where the often uninjured latissimus dorsi can be used as a pedicled flap to cover a very large area, to provide a blood supply and thereby to promote healing. This requires, however, that adequate equipment and staff be available. It is extremely awkward to lose a local flap due to technical errors. Debridement may result in a clean wound which allows one to use a large plate under the perfectly vascularized flap (Fig. 7). Even under such circumstances the far cortex is not exposed, and a free butterfly is not touched to allow undisturbed healing. The internal fixation technique may be modified using e.g. combinations of plate and external fixator.

It appears firmly established that the rapid reconstruction of the soft-tissue envelopment is more critical than immediate bony reconstruction. Soft-tissue coverage should be restored within 3 days after injury [3, 7]. The failure rate of free flaps has been shown to increase in later reconstructions namely due to venous problems [7], and longer periods of deprivation of the blood supply to the bone will result in desiccation and osteonecrosis, and the potential for revascularisation through transposed muscle is lost. If muscular soft-tissue coverage is ascertained, however, the fracture site is not only protected from infection [3, 7] but the transposed mus-

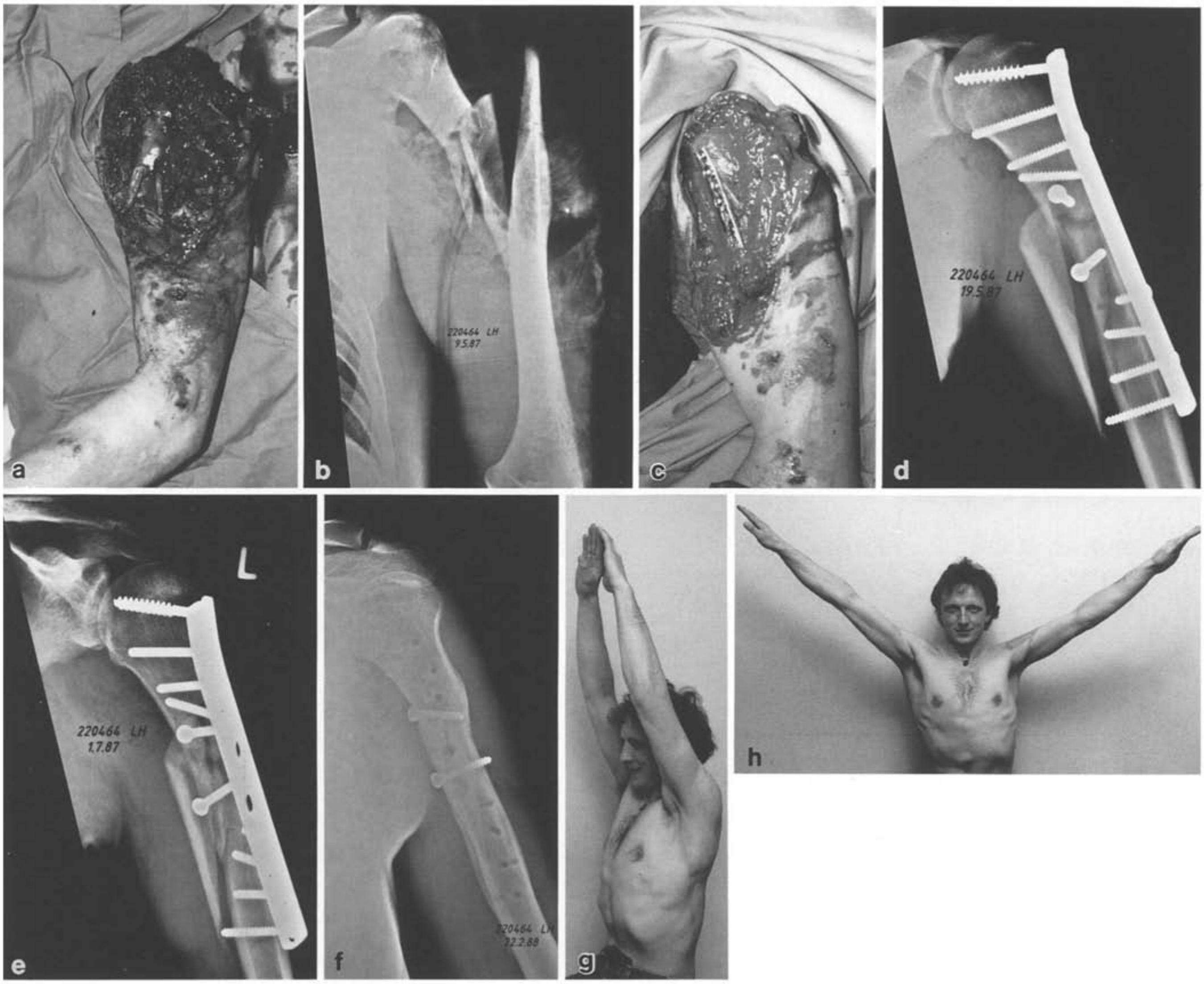

Fig. 7a–h. Explosion injury of the left arm causing a stage III lesion of the upper arm (**a, b**) with destruction of the lateral and anterior deltoid. Meticulous debridement to an essentially clean wound (**c**) allowed plate fixation. The medial butterfly is not visualized and left alone (**d**). A pedicled M. latissimus dorsi flap is used to cover the defect in the same procedure. Bony healing is rapid (**e, f**). The esthetic result is satisfactory, and the functional result is excellent (**g, h**)

cles provide blood supply to the fracture site and substantially increase the speed and quality of the healing process [23, 24].

Conclusions

Trauma centers see more and more extremely difficult fractures sustained after high-energy trauma, often affecting multiply injured patients. Although these fractures are classified according to the pattern of bony injury [19], the soft-tissue component has a decisive role in the selection of the treatment method and the choice of implants. Optimal soft-tissue conditions are the prerequisite for the healing of all fractures; if the soft tissues are destroyed, their surgical replacement with viable tissue prevents infection, promotes bony healing [7, 12, 23, 24] and helps to restore function. Routine administration of prophylactic antibiotics has proven to be a valuable adjunct [21, 30]. Careful pre-operative planning, indirect reduction techniques [17] and better knowledge of the vascular anatomy of the limbs permit us to use less traumatic fixation techniques which combine the advantages of internal fixation with those of closed functional treatment of fractures. The application of the minimal-optimal techniques of osteosynthesis is demanding; they need to be incorporated into the armamentarium of the surgeons who treat such patients as they have proven to be successful, presumably because they are more "biological".

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