Facts of Fractures of the Hand

Feiten over Hand Fracturen

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Contents

Introduction

Incidence

Hand fractures occur frequently: the annual incidence of phalangeal fractures in the normal population is about 0.1-0.3%, of metacarpal fractures about 0.1-0.2%[1-4]. These fractures account for between 0.2% and 3% of all patients visiting an accident and emergency unit [2,5,6].

Treatment

Hand fractures differ from fractures elsewhere in the body due to anatomy and function of the hand. The hand consists of a group of extremely mobile bones, surrounded by ligaments and tendons in a complex interaction, leaving very little room for failure in fracture healing. Functional restoration demands correct length, alignment and rotation of bone, and early mobilization[7-9].
Uncomplicated, undisplaced, and stable phalangeal or metacarpal fractures (at presentation or after reduction) can be managed conservatively by reposition, casting, splinting, or early motion; sometimes even follow-up is considered not strictly indicated[66,10-13]. Surgical treatment is indicated when the fracture is displaced and reduction is not possible. Surgical treatment is also indicated when the fracture is unstable after reduction, or when there is substantial associated soft tissue trauma. In surgical treatment, reduced bone fragments are fixated by an internal or external device, denominated 'osteosynthesis'. There are many different osteosynthesis modalities, all of which have to meet the following requirements:

- stable enough to permit fracture healing
- preferably biologically inert or resorbable
- has to allow for some micro motion, permitting endosteal and periosteal callus formation
- has to minimize (further) damage to already impaired circulation of fracture fragments
- has to allow early mobilisation[9,10,14].

Sequelae

Most finger and metacarpal fractures heal adequate in short time, without functional sequelae[6,12].
Although today's technology (anaesthesia, antibiotics, technologically advanced implants) allows considerable freedom in treating these injuries, still a number of patients suffer a complicated course of events and experience stiffness, nonunion, malunion, and chronic pain following hand fractures[10].
Not only patients suffer from complicated hand fracture healing, also costs for society in workers' compensation and medical costs can be substantial[4,15-18].

The future of hand fracture treatment lies in improving our ability to choose and properly apply appropriate treatment for the variety of patients and fractures that present, bearing in mind that each patient's perspective of an optimal outcome is different[10].

Thesis
To assess the results of treatment of phalangeal and metacarpal fractures and identify opportunities for improvement, we performed a couple of studies that led to this thesis.
These studies were performed at the department of Plastic, Reconstructive and Hand Surgery and at the Accident and Emergency Unit of the Erasmus University Medical Center, Rotterdam, the Netherlands.

In order to search for best practices in fracture treatment of phalangeal fractures, a literature study was performed. With the results of this literature study, we aimed to compile an evidence-based protocol and manual of operative treatment of fractures of phalanges (*chapter 2*).

In order to compare the results of operative phalangeal fracture treatment of the department of Plastic, Reconstructive and Hand Surgery to results in published series, a retrospective assessment of results was done for both bony healing and functional outcome (*chapters 3 and 4* respectively).
In these studies, we were also interested to identify risk factors for complicated healing (*chapter 3:* complicated bony healing - malunion, nonunion, or infection; *chapter 4:* diminished function of the affected finger). Identification of these risk factors might improve our future results when treating patients with these risk factors. Furthermore, we were interested in prognostic data. More specific, we aimed to answer the following question: is it possible to predict the objective functional loss of a digit, following a specific fracture or fracture treatment? We defined the functional loss in chapter 4 as 'loss of degrees of total active motion of the digit'.

Since functional outcome is not only a mere product of objective measurements of digital and hand function, we also studied the impact of healing of finger fractures on a subjective outcome scale - the Disability of the Arm, Shoulder and Hand score- and analyzed the relationship with objective measurements: the American Medical Association impairment rate (*chapter 5*).

From our literature study and results from our own series, we designed a tailored fracture treatment protocol for metacarpal and phalangeal fractures, to be used by all hand fracture treating specialists in our hospital: Traumatologists, Orthopaedic surgeons and Plastic surgeons. After approval by the medical staff of these specialisms, this protocol was distributed to all residents and specialists involved in fracture management at the Accident and Emergency Unit. In a prospective study, results of working with this evidence-based protocol were studied, in an effort to quantify the quality of treatment of phalangeal and metacarpal fractures in our hospital, and identify improvement opportunities (*chapter 6*).
In the current finance-driven health care system, medical problems are not so much content-driven anymore, but more defined by costs involved.

A perspective on possible future cost reductions might enhance the urgency to improve the quality of treatment of these fractures. In a prospective study, we quantified and identified variables influencing the hospital costs of metacarpal and phalangeal fracture treatment, the number of days off work, the number of days of hospital admittance, the number of operations, and the number of outpatient clinic visits (*chapter 7*).

In the discussion (*chapter 8*), results of the aforementioned studies are briefly discussed, an analysis is made whether the results have met the purpose of this thesis, and future actions are described.

Aim

Summarizing, the aim of this thesis was to answer the following questions:

- What is the state of the art in operative phalangeal fracture treatment?
- What are the results of bone healing in operative phalangeal fracture treatment in our department, as compared to published series? What are the risk factors for impaired bone healing?
- What is the objective functional outcome following operative phalangeal fracture treatment in our own series? What are the risk factors for diminished functional outcome? Can we predict functional outcome?
- What is the relationship between objective functional outcome and subjective functional outcome data?
- Does phalangeal and metacarpal fracture treatment according to protocol lead to good results in our hospital? Why (not)?
- Is the impact of phalangeal and metacarpal fracture treatment substantial enough - in an economic and logistic perspective - to warrant improvement of (organisation of) care?

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Operative management: Indications and results of phalangeal fractures

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Introduction

Phalangeal fractures of the hand are among the most commonly fractured bones in the body. They are mostly discarded and considered as minor injuries without hardly any consequences. However, inaccurately treated and overlooked phalangeal fractures can lead to significant disability.
It cannot be emphasised enough that the soft tissue envelope condition is of utmost importance to fracture healing, especially in the frequent crush injuries.
Phalangeal fractures can be subjected to deforming forces of both the intrinsic and extrinsic tendons of the muscles of the hand and forearm. Therefore these fractures require careful assessment as to their intrinsic stability and potential for deformity[1]. Seemingly small fractures can result in lasting impairment owing to malunion, stiffness and tendon adhesions, even in the hands of experienced physicians (see fig. 1A and B).
As for all diaphyseal bone fractures, fracture healing of the phalanges of the finger is likely to take place according to one of the following principles: primary bone healing, secondary bone healing, or nonunion[2]. Stable fixation and interfragmentary compression, a sufficient vascularity, and a good bone to bone contact are basic requirements for proper bone healing.
In cases where there is insufficient immobilisation, insufficient bone contact, associated soft tissue loss, or compromised vascularisation, or where the amount of bone loss, location, or general medical condition interfere with proper bone healing, a mal- or nonunion may evolve, leading to poor function of the involved digit.
Also, early mobilisation is mandatory in order to prevent stiffness of capsulogenic or tendinogenic origin (caused by adhesions, especially following tendon repair). Therefore, in the ideal situation, sufficient stability should be obtained for fracture healing to occur, while at the same time, a complete freedom of motion should be guaranteed for soft tissue structures to be practised in order to prevent adhesions.

Classification

Phalangeal fractures can be classified according to various principles:
- closed or open
- stable of unstable
- undisplaced or displaced (also: shortening? rotation? angulation?)
- intra- or extra-articular
- location within the phalanx: head, neck, shaft, base
- geometry: transverse, oblique, spiral, comminutive, avulsion, vertical, impression (see fig. 1C and D)
- association with ligament, tendon, or neurovascular injuries

Figure 1:

a) Rotation and deviation following conservative treatment of a P2 spiral fracture

b) Same case as a), spiral fracture healed with rotation and tendon adhesion with impairment in handling

c) P2 oblique fracture; P1 transverse fracture;

d) Different comminutive fractures of P2 of three digits

Fig. 1a

Fig. 1b

Fig. 1c

Fig. 1d

Incidence and etiology of phalangeal fractures

The overall incidence of metacarpal and phalangeal factures is 10% of all fractures. Phalangeal fractures alone account for approximately 6.5% of all fractures. The border digits are most commonly injured and more than 50% are work related. The site of injury is in 45-50% in the distal phalanx with associated nail bed injury; 30-35% metacarpal fractures; 15-20% proximal phalanx fractures and 10-12% middle phalanx fractures. The mechanism of injury being torque, angular force, compressive load and direct blow in non-epiphyseal fractures. In epiphyseal fractures the mechanism is avulsion, shear and splitting by compressive load.

In a large survey of 235,427 patients admitted to the Emergency Unit at the University Hospital Groningen in The Netherlands, 6,857 patients (2.9%) sustained respectively one (98.6%) and multiple (1.4%) fractures involving the phalanges of the hand. The male to female ratio was 1.8:1.
Sport injuries were the leading cause in this particular survey in the 10 to 29 year age group. In the group over 70 years falls were the main cause.
In men, the 40 to 69 age group had the highest incidence of phalangeal fractures of the whole population, machinery injuries being the dominant cause in this group. In children under 10 years of age compression injuries were the leading cause[3].

In a more selected prospective study of 924 fractures of phalanges (811) and metacarpals (113) in 765 patients (1.06 phalangeal fractures per patient) described by the group of Chow from Hong Kong, the male to female ratio was 6.9:1. The majority occurred in a crush injury (62.1% out of 8 items for classification) and 67.3% were known to be work-related. In this study 72.9% of the fractures were extra-articular, 28.1% had associated injury and 48.1% were operated upon with open reduction and internal fixation[4].

In our clinical series in Rotterdam of 737 fractures of phalanges in 371 patients (1.99 phalangeal fractures per patiënt; all were referrals and all were operated), the male to female ratio was 8.5:1. Distribution of fractures is depicted in figure 2. The majority occured in a crush injury (53.7% out of 6 items), 49% of the fractures were extra articular and 65% had associated injury, tendon and neurovascular injury. Nearly all fractures were open.
The predominant geometry of the fracture was comminutive 62.6% followed by transverse 14.9% and oblique 8.5% out of 7 items.

Indications for surgery

The vast majority of isolated phalangeal fractures can be treated successfully by nonoperative means; fractures that are closed, well aligned, and stable at presentation as well as those that present with deformity but are stable after a closed manipulative reduction.

Indications for surgical treatment of a phalangeal fracture are[1,5,6]:

- fractures that cannot be reduced nonoperatively
- fractures that are unstable following reduction
- comminutive fractures
- midshaft displaced fractures
- articular fractures with displacement
- spiral fractures
- fractures that cause rotation and/or shortening of the digit
- fractures that are associated by a substantial amount of soft tissue trauma, necessitating surgical intervention by itself: fractures associated with devascularising injuries, nerve or tendon injuries or complete amputations.

Relative indications are:

- closed, malaligned fractures
- fractures in noncompliant patients[7].

Figure 2:
Phalangeal fracture distribution in our clinical series:

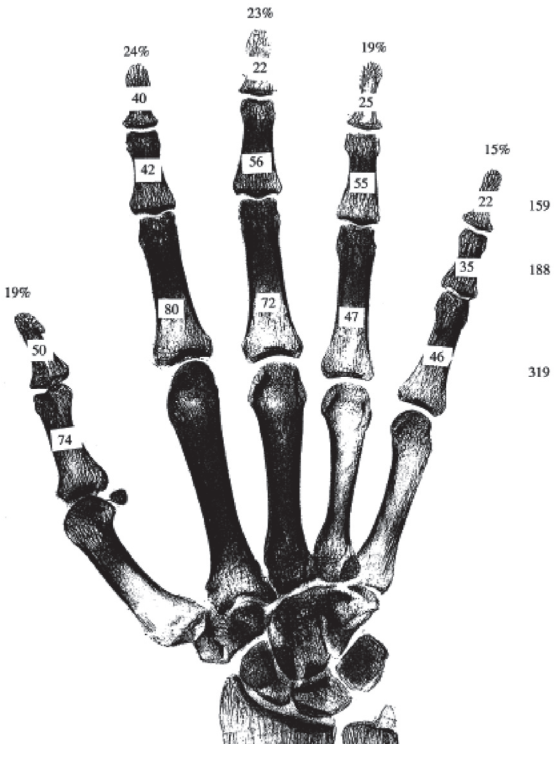

Fig. 2

Techniques

Immobilisation techniques depend on the location, type of fracture, and surgeon's preference. A system of fixation, internal or external must be able to withstand the deforming forces of intrinsic and extrinsic musculature to provide sufficient stability for fracture healing, either primary or secondary to occur. At the same time, soft tissue structures need to be mobilised as soon as possible in order to achieve adequate functional results[1,6].

Various techniques have been developed for stabilisation of phalangeal fractures: K-wires, cerclage, plates and screws, intramedullary fixation, external fixation, stapling, traction, each with its advantages and limitations:

- K-wire fixation: least difficult, cheap, lacks rigidity. A single K-wire gives no protection against rotation. Crossed oblique K-wires are most commonly used. They should not cross at the fracture site as they will result in distraction. Prevent penetrating the joint capsule, collateral ligaments of the adjacent joints and extensor or flexor mechanisms. K-wires can either be used to fix fractures in open reduction or percutaneously following closed reduction. K-wires penetrating the skin lead more frequently to pin tract infection, especially when they become more loose after a couple of weeks. Buried just beneath the skin is preferable. Percutaneous pinning is best for closed shaft fractures[8]. Longitudinal K-wires traversing one or more joints should be splinted to prevent breaking of the wire. K-wire diameters mostly used in hand fractures range from 0.6 - 1.25 mm.
- Interosseous wiring: more difficult, not rigid, often combined with K-wire(s). The wiring provides a more compressive force. Mostly used is wire with a diameter 0.4 and 0.5 mm; (see fig. 3A and B)[1,9].
- Tension band technique: combination of above techniques parallel K-wires with cerclage wire in a figure of eight gives good compression and is especially suitable for arthrodesis. It is also possible in transverse shaft fractures[1].
- Interfragmentary screws: more difficult, accurate reduction is necessary, good compression, use of two screws provides more rigidity, depending on the size of the fragment (see fig. 4A and B).
- Plate and screws: more difficult, also accurate reduction necessary, rigid fixation, spatial device, extensive exposure necessary compromising vascularity of the bone[10-12]. Screws should not penetrate the fracture line, early active and passive mobilisation is possible (see fig. 5A and B). Plate and screws can either be non-resorbable or resorbable.
- Intramedullary fixation: longitudinal or bend wires and rods, less rigid, can be combined with interosseous wiring. Especially used in transverse and comminuted shaft fractures[13].
- Staples: especially memory staples give good compression in transverse or oblique fractures. They are not suitable for comminutive fractures. One staple does not always prevent rotation.

- External fixation: many different devices are available for hand fractures. The combination of strength together with small size and light weight is preferred. They are mostly used to maintain bony length in fractures with bone loss and significant soft tissue injury, preventing initial internal fixation (see fig. 6A to D)[14].
- Traction: especially for comminuted intra articular fractures[14].

When a substantial amount of bone tissue has been lost at the trauma, a graft of cancellous bone, for instance peroperatively harvested from the distal radius, is advised if the soft tissue envelope is sufficient.

In our series of 737 multiple phalangeal fractures K-wires with or without interosseous wiring were used in 79.2% of the cases, 15.8% with plates and/or screws and 5% by external fixation.

Figure 3:
a) P1 oblique comminutive fracture
b) Kirschner wire and cerclage osteosynthesis

Figure 4:
a) Spiral fracture
b) Lag screw osteosynthesis

Fig. 3a

Fig. 3b

Figure 4a

Figure 4b

Figure 5:
a) P1 transverse comminutive fracture
b) T-plate and screws

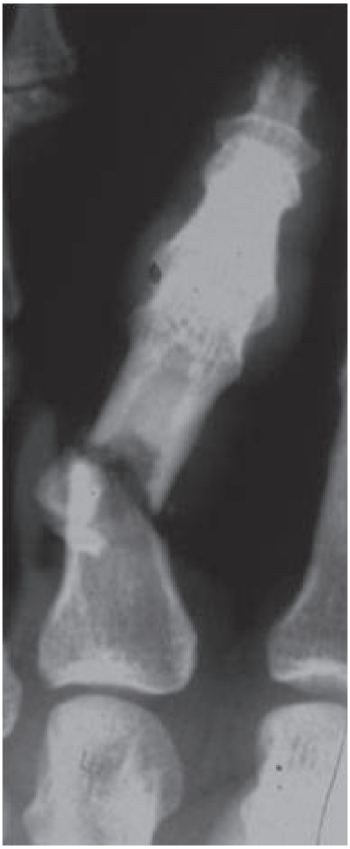

Figure 5a

Figure 5b

Figure 6:
a) P1 spiral comminutive fracture with bone loss
b) External fixation and bone graft
c) Same case: external fixation and bone graft
d) Same case: end of surgery

Figure 6a

Figure 6b

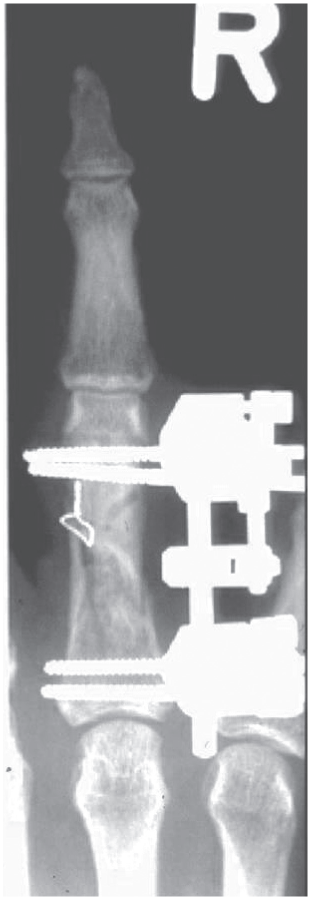

Figure 6c

Figure 6d

Treatment

Normal hand function is the ultimate goal and not a perfect X-ray. When history is taken specific questions should be asked apart from the mere cause of the injury. Like: how long compressed?; the site of the impact?; the thickness of the blade of the saw?; hand dominance?; profession?; etc. Symptoms should correlate with the X-ray. On examination deformity, swelling and tenderness should be recorded, as well as joint stability established with care (especially in the metacarpophalangeal joint), tendon function and neurovascular status. X-rays include AP, lateral and oblique views of the fingers and/or hand. Oblique views are helpful in small fractures and fractures near joints. Following the diagnosis a treatment plan is made suitable for the particular patient, taking into regard occupation, life style, hobbies, age, medical condition, etc. Usually there are more treatment options. The patient should be informed about the treatment options and preferably participate in the discussion. In the decision making process it should be kept in mind that rotational deformities become more significant if the fractures are more proximal. In closed fractures it is still possible to reduce fractures within approximately ten days. After three weeks it is mostly not possible anymore. In open stable fractures without associated injury appropriate wound care can be sufficient. If unstable with or without associated injury, direct reduction should be performed. The method of fixation depends on the location of the fracture and the condition of the soft tissue envelope[1,6,14,15].

As this chapter is only concerned with the operative treatment of extra-articular phalangeal fractures, no further attention will be paid to conservative management or operative treatment of intra-articular fractures.

Specific fracture treatment

Fractures of the distal phalanx
Fractures of the distal phalanx can be classified as tuft, shaft, base and epiphyseal fractures. Because of the close relation of the distal phalanx with the finger pad as well as the nail bed, there is often damage to these soft tissue structures in distal phalanx fractures. Nail matrix injuries should be repaired meticulously to prevent nail deformities and subungual hematomas should be drained. If possible, the nail should always be preserved, it can even be used as a splint[6].

In a prospective study of 110 fractures of the distal phalanx 70% did not recover fully within 6 months. Describing symptoms such as difficulties with picking up small objects, writing, buttoning, typing, playing instruments, etc. One in three had cold hypersensitivity. Subungual hematoma increased the likelihood of abnormal nail growth by a factor of four[16].

In our clinical series of 737 phalangeal fractures 80 were classified as extra-articular fractures of the distal phalanx; 40 fractures of the tuft type, 32 of the shaft and 8 of the base. 49 were crush injuries and 45 were comminuted. Only K-wire osteosynthesis with or without interosseous wiring was used in this group, resulting in the following complications: 4 cases of nonunion and 4 cases of deviation or rotation. Deviation is defined as being deviated from the longitudinal axis on the X-ray.

Operative management of extra-articular distal phalanx fractures can involve:

- Tuft fractures
  These fractures are often open, due to soft tissue damage following crush or avulsion. It can include approximation of small fracture fragments, repair of soft tissues, drainage of hematoma up to 48 hours and splinting of the finger. Within 2-3 weeks limited light use and within 6 weeks full use should be possible. Nail deformities are common. However, less than 30% of tuft fractures will recover fully at 6 months. Comminuted tuft fractures without osteolysis did four times better than fractures with osteolysis[16].
- Shaft fractures of the distal phalanx
  These fractures occur following direct crush or blunt impact and are usually open and minimally displaced. If the fracture is unstable following reduction, a percutaneous K-wire can be placed. If the fracture is close to the base, the DIP joint should be crossed. The K-wire should not be too close to the nail bed in order to avoid damage. The tendon of the deep flexor can pull the proximal segment volarly and cause malunion. Nonunion can occur following soft tissue interposition; open reduction and internal fixation should then be performed with bone graft when necessary. Full use will be at about 6 to 8 weeks. Early use of MCP and PIP is mandatory.

- Base fractures
  These fractures are mostly intra-articular and are not discussed in this chapter.
- Epiphyseal fractures of the distal phalanx
  Not discussed in this chapter.

Fractures of the middle phalanx
Displacement, angulation and rotation can easily occur with fractures of the middle phalanx, following industrial accidents and crushing injuries. As the flexor and extensor mechanism are very close to the bone, tendon adhesions can occur, diminishing function of the finger. The PIP and DIP joint are prone to fibrosis and capsular contracture, even when the fracture is extra-articular. Detailed care is essential.

In our clinical series of 737 phalangeal fractures 77 were classified as extra-articular fractures of the middle phalanx: 11 of the distal type, 55 of the shaft type and 11 of the proximal type. 49 were crush injuries and 32 were comminuted. K-wire osteosynthesis with or without interosseous wiring was mostly used, other osteosynthesis techniques (plates and screws, external fixation) in 11 cases. In total 4 cases of nonunion and 8 cases of deviation or rotation were diagnosed.

- Distal fractures of the middle phalanx
  The proximal segment is tilted volarly by the superficial flexor tendon and the distal segment dorsally by the terminal extensor tendon mechanism. The most common is the transverse distal fracture which is severely angulated and difficult to reduce. If closed reduction fails, open reduction and internal fixation is necessary. When percutaneous K-wires are used, they can be removed in 4 to 6 weeks. In more rigid fixations active motion can start earlier. Full use will be at 8 to 12 weeks.
- Shaft fractures of the middle phalanx
  In the shaft, spiral and oblique fractures are most common, giving less displacement. If the finger does not scissor following closed reduction and is stable, no operation is needed. A perfect X-ray is not necessary. In unstable fractures, directly or after follow-up at one week, after closed reduction attempts, open reduction and fixation should be performed. A few millimetres shortening does not impair function in most instances. In oblique and spiral fractures lag screws are preferred, although others prefer percutaneous pinning[8]. When K-wires are used, they should be removed in 4 to 6 weeks. Light use of the finger after 4 to 6 weeks; full use in 8 to 12 weeks. Hand therapy should start within days following trauma.
- Proximal fractures of the middle phalanx
  These fractures are usually intra-articular and not discussed in this chapter.

Fractures of the proximal phalanx
Rotation and angulation in these fractures can result in loss of range of motion, tendon adhesions and stiffness, especially of the MCP and PIP joints. Therefore stable reduction and early motion of tendons and joints are very important. Proximal phalanx fractures have the highest complication rate.

In our clinical series of 737 phalangeal fractures, 152 were classified as extra-articular fractures of the proximal phalanx: 20 of the distal type, 118 of the shaft type and 14 of the proximal type. Eighty-four fractures were caused by crushing injuries and 85 fractures were comminuted.
K-wire osteosynthesis with or without interosseous wiring was mostly used, other osteosynthesis techniques (plates and screws, external fixation) in 23 cases. In total 9 cases of nonunion and 16 cases of deviation or rotation were established on the X-ray.

In a prospective study by Chow's group concerning unstable proximal and middle phalangeal fractures (52 cases) treated by screws and plate fixation, there was no significant improvement in the results as compared to K-wire fixation. Only 26.9% had good results, largely due to poor prognostic factors[12].

- Distal fractures of the proximal phalanx
  These are often intra-articular through one or both of the condylar heads and not discussed in this chapter.
- Shaft fractures of the proximal phalanx
  Usually these fractures are oblique or spiraling. Mostly a few millimetres of shortening can be accepted, depending on the profession of the patient. When angulation is greater than approximately 10% and in comminuted fractures, open reduction and internal fixation is recommended. Depending on the amount of soft tissue injury the incision can either be dorsal, splitting or elevating the extensor mechanism or lateral, elevating the lateral wing. The oblique and spiral fractures can best be treated with lag screws when unstable. Also 2 to 3 transverse percutaneous K-wires can be considered in these cases. In transverse fractures either K-wires, interosseous wiring and miniplates are available. If a plate is used I prefer to place it on the lateral side, to prevent tendon adhesions, although many authors advocate a dorsal plate[17-19]. When bone loss is present, bone grafts are advised.
  In comminuted fractures, patients should always be explained the possible necessity of a bone graft, for instance from the distal radius. Within a few days hand therapy is started. Frequent X-ray follow-up should be performed in the first three weeks. K-wires are removed in 4 to 6 weeks. Light use can be started at 4 weeks in rigid fixation and 6 to 8 weeks with K-wires. Full use depending on the job in 8 to 12 weeks. Full recovery takes a long time depending on associated injuries.

- Proximal fractures of the proximal phalanx
  In adults, proximal fractures of the proximal phalanx are often transverse, angulated and unstable. The proximal fragment is volarly flexed by the interossei. A dorsal approach gives access to the proximal phalanx and joint, following tendon splitting. Small plates and screws are preferred (T-plate or condylar pin plate). K-wires are not a rigid fixation, but prevent angulation. They can be removed after 4 to 6 weeks following which light use can start. Full activity can be achieved in 8 to 12 weeks, depending on the soft tissue injury. Prevent MCP extension contracture by splinting in flexion from 60 to 90 degrees. The PIP joints should be splinted in extension. Fibrosis of the capsule occurs easily. Neglect can be devastating!

Postoperative therapy
Following assurance of the stability of the fixation postoperative therapy can begin. Rehabilitation should include reduction of swelling, early mobilisation, and splint support. These methods are necessary to prevent articular stiffness, tendon adhesion, and overall impairment. A certain amount of responsibility can be expected of the patient in the active mobilisation of the involved digit or digits. To minimise swelling coban wraps can be used in combination with the use of static and dynamic splints[1].

Complications
The complication rate is significantly higher in: intra and peri-articular fractures versus extra articular fractures; the middle 1/3 versus proximal 1/3 fractures; open versus closed; extensive versus minimal injury; and bone grafted versus non bone grafted fractures[11].

The main complication in the treatment of phalangeal fractures is loss of motion as a result of tendon adherence and stiffness of adjacent joints, in particular the PIP-joint. Tenolysis can improve active motion, however extensor tenolysis has disappointing results on PIP-extension.
In flexor adhesions the superficial flexor tendon can be excised, however we rarely do so. Mostly a tendon transplant is performed in cases with severe adherence. In PIP flexion contractures in severely injured fingers usually an arthrodesis is performed. We prefer tension band wiring as internal fixation for arthrodesis.

Infections can occur as a pintract infection, following percutaneous wiring. Extraction and antibiotic treatment will often be sufficient in these cases, although more stiffness will be encountered. Infections can also lead to malunion or nonunion. In our clinical series of 737 phalangeal fractures (nearly all open) 15 infections occurred (2.0%), resulting in 3 nonunions.
13 infections were comminutive fractures equally distributed over intra- and extra-articular fractures. In other series with high associated injuries up to 8% infections are described[20].

Malunion is more common in proximal phalanx fractures. Volar angulation can occur near the base resulting in malunion. Treatment can be an opening wedge osteotomy and bone graft, or closed wedge osteotomy.

Malrotation mostly occurs in spiral or oblique fractures of the proximal and middle phalanx. Depending on the degree of malrotation correction can be performed by either an osteotomy at the metacarpal or phalangeal level. Lester advocates a more aggressive manner in subacute malaligned fractures, performing corrective osteosyntheses or arthrodeses in appropriate cases in an early stage[21], usually however corrections are performed at a later stage.

Nonunion occurs in approximately 1% of all phalangeal fractures[5,20]. It is a result of bone loss, soft tissue interposition, fracture motion or distraction at the fracture site. Treatment should be resection of non-viable bone with the addition of stable fixation and bone grafting. In our selected clinical series of 737 phalangeal fractures, nearly all were open with 1.99 fractures per patient and 65% associated injury (tendon and neurovascular). We encountered 40 cases of nonunion (5.4%) necessitating a second procedure. Associated soft tissue trauma was a significant risk factor ($P < 0.05$) for nonunion in our series. In other selected series, nonunion rates up to 6.6, 7.8 and 10% are described, also highly correlated with associated soft tissue injury[12,22,23].

Summary

The majority of isolated phalangeal fractures can be treated successfully by non-operative means. Closed reduction and percutaneous pinning can be suitable for closed, simple, unstable fractures of the shaft without associated injury. Open reduction and internal fixation are suitable for closed and open, unstable fractures, either simple or compound, with or without associated injury. K-wire fixation gives less rigidity and usually requires extra immobilisation to protect the fixation. Plates and screws and other implants provide more stability and therefore early active mobilisation. However these techniques can be technically very demanding. In the more complex trauma of the hand with associated injury, stable fixation with an early opportunity for mobilisation is essential. The soft tissue envelope condition is of utmost importance. Complications can be significant even in experienced hands with adequate early therapy postoperatively.

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Treatment of phalangeal fractures in severely injured hands

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Abstract
This retrospective study was performed to assess the incidence of complications of operative treatment of phalangeal fractures. Risk factors for the development of complications were also investigated. Records and radiographs of 350 patients with 666 operatively treated phalangeal fractures were studied. Minimum follow-up was 1 year.
A total of 176 fractured fingers were amputated primarily or secondarily, leaving 490 fractures for follow-up. Ninety-three fractures were treated conservatively. Nonunion necessitating reoperation developed in 6% (31/490) of fractures, malunion in 9% (44/490) and infection in 2% (8/490). Infection, segmental bone loss and (neuro)vascular injury predisposed to nonunion and replantation predisposed to malunion. There was a statistical correlation between the use of external fixation and malunion. Nonunion, malunion, and infection rates were similar to other studies.

Introduction
The annual incidence of phalangeal fractures in the hand is about 0.1% in the normal population[1] and these injuries account for between 0.2% and 3% of all patients visiting an accident and emergency unit[2,3] and between 12% and 46% of all hand fractures[3,4]. Most fractures are uncomplicated, undisplaced and stable at presentation or after reduction and these can be managed conservatively[2,5]. Surgical treatment is necessary when the fracture is displaced and reduction is not possible, or when the fracture is unstable after reduction. If the fracture is spiral or comminuted, or when midshaft or articular fractures occur with displacement of fragments, surgical treatment is also indicated. Finally surgical treatment is preferred when there is substantial associated soft tissue trauma.

Infection, malunion, or nonunion may develop after surgical fixation and the patient may suffer significant disablement. There is a great variation in the reported incidences of infection (0-8%), malunion(0-28%), and nonunion (0-9%)[6-20]. Most studies address only specific fracture types or specific types of osteosynthesis[1,2,7,10,13,21-28]. In some studies results are relatively good because conservatively managed or stable, uncomplicated fractures are included or replantation procedures are excluded[1,5,9,19,29,30] . In order to assess the incidence of complications of operative treatment of phalangeal fractures in a clinical series, a retrospective study was carried out.
Risk factors for the development of complications were also investigated.

Patients and methods
The records and radiographs of all patients with one or more phalangeal fractures that were surgically treated in our department between January 1980 and June 1997 were studied. The records were investigated for mode of injury, the presence of associated soft tissue injuries, the details of the operation, and the follow-up. The radiographs were studied for fracture

geometry, location of the fracture(s), osteosynthesis, consolidation, and the reduction achieved. A nonunion was scored if after 6 months there were no clinical or radiological signs of consolidation. Malunion was defined as any rotation, angulation, deviation or shortening of the involved digit on physical examination or on X-rays, regardless of functional impairment. Infection was a clinical diagnosis based on the development of a fistula or on the intraoperative findings at re-exploration for nonunion.

A total of 367 patients with 718 phalangeal fractures were operatively treated in the study period. Sufficient data could be retrieved in 350 patients with 666 fractures with a minimum follow-up of 1 year. Statistical analysis was by multiple regression analysis. Significant variables were entered simultaneously into the analysis to generate p-values. A p-value < 0.05 was considered to be statistically significant.

Results

Six hundred and twenty-two fractures were seen in 315 men and 44 fractures in 35 women, resulting in a 9:1 sex ratio and a total of 666 fractures. The mean age was 35 years (range: 8-80 years) and, on average, there were 1.9 fractures per patient (range: 1 to 9). Almost all fractures were complicated and in 68% there was a significant associated soft tissue injury, such as a tendon injury or an injury to the neurovascular bundle. In 322 cases the extensor apparatus was lacerated, in 312 there was a uni- or bilateral neurovascular lesion and in 242 cases the flexor tendons were severed.

Fifty-one percent of fractures were intra-articular. Eighty-six percent of fractures (573/666) were operatively treated, while 14% (93/666) of the (concomitant) fractures were not osteosynthesized during operation. The distribution of fractures in the phalanges and digits is shown in Figure 1. The index finger was most often affected, and most of the fractures involved the proximal phalanx. As Table 1 demonstrates, crush was the most common mode of injury and most fractures were comminuted.

Figure 1: *Distribution of fractures over phalanges*

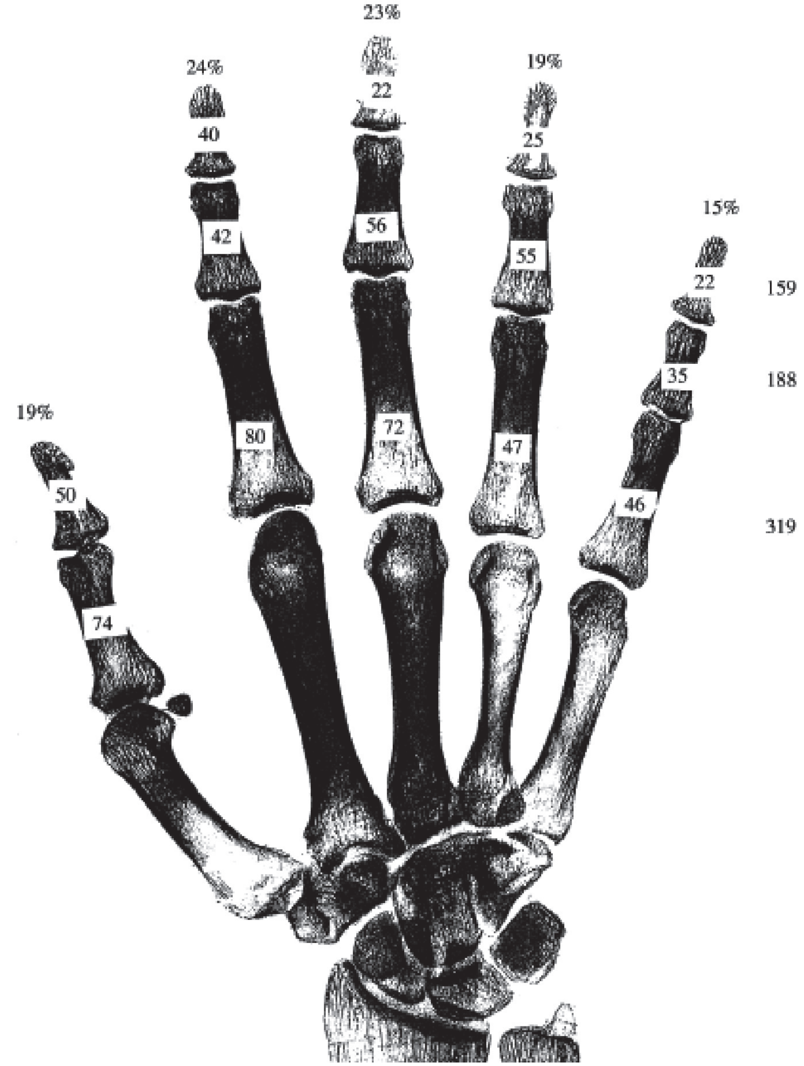

Figure 1

__Table 1:__ Distribution of modes of injury and type of fracture. In nine patients no data about the mode of injury could be retrieved.

		Mode of injury				
	Type	Crush	Saw	Explosion	Other	Total
Geometry	Avulsion	30	10	2	12	54
	Transverse	54	20	13	10	97
	Oblique	32	15	5	10	62
	Spiral	12	5	2	7	26
	Vertical	4	2			6
	Impacted	7	3		7	17
	Comminuted	205	117	33	40	395
	Total	344	172	55	86	657

Ninety-nine fractured fingers were amputated primarily by the trauma and could not be reimplanted and 77 had to be amputated during operation as a result of extensive bone and soft tissue injury (in all 176 cases; 26%).

Since 176 of the 666 fractures were amputated, 490 fractures were left for follow-up of which 397 were osteosynthesized during operation. K-wire(s) and/or interosseous wires were used in 317 (80% of osteosynthesized) fractures, lag screws in 52 (13%), plate and screws in 21 (5%), external fixation in 19 (5%), and traction in 3 (1%). Ninety-four percent (459/490) of non-amputated fractures showed consolidation, in 9%(44/490) there was a malunion and in 2% (8/490) an infection developed. In 16% (80/490) a second operation was necessary due to nonunion, malunion, or malfunction.

Statistical analysis showed that infection ($p<0.005$), segmental bone loss ($p<0.01$) and associated soft tissue injury ($p<0.05$) were risk factors for nonunion (Table 2). Replantation of an amputated digit ($p<0.0001$) and the use of an external fixator ($p<0.0001$) both predisposed to malunion (Table 3). Fracture geometry, the phalanx involved, osteosynthesis technique, mode of injury, sex, and age did not influence the rates of nonunion or malunion.

Table 2: *Risk factors for nonunion.*

	Consolidation	Nonunion	Total	P-value
No infection	455	27	482	<0.005
Infection	4	4	8	
No bone defect	404	21	425	<0.01
Bone defect	55	10	65	
No associated injury	201	7	208	<0.05
Associated injury	258	24	282	
Total	**459**	**31**	**490**	

Table 3: *The effect of replantantion and the use of external fixation on malunion and nonunion.*

	No malunion	Malunion	Nonunion	Total
No amputation	375	28	24	427
Subtotal amputation	27	4	6	37
Total amputation	15	10	1	26
No external fixation	407	35	29	471
External fixation	10	7	2	19
Total	**417**	**42**	**31**	**490**

Discussion

The rate of 1.9 fractures per patient is higher than in previous reported series[20] and can be explained by the fact that this study focused on relatively severe injuries, necessitating hospital stay and operative treatment. Moreover, referrals come to our clinic from a large area with heavy industry. The study of Ip et al. is comparable to our study and reported a male to female ratio of 7:1 and a 67% prevalence of work-related injuries (versus 79% in our series), with crush being the most frequent mode of injury (62%)[9].

Our nonunion, malunion and infection rates are comparable to other, similar studies despite the severity of injury in our series[9,23,29,30]. The relationship between infection and nonunion[30] was confirmed in our study.

Segmental bone loss predisposed to nonunion in our series. Proper bone healing needs good bone contact and stable fixation[27,31]. Insufficient contact between the fracture fragments, caused by segmental bone loss, precludes such healing. For fractures with segmental bone loss a graft of cancellous bone is advised[26-28,32,]. In 23 of our fractures a cancellous bone graft was used and resulted in consolidation. Nonunion occurred in ten fractures with segmental bone loss (one of which was treated conservatively); in only one of these fractures cancellous bone graft was used. Associated soft tissue injury was also a risk factor for nonunion in this study and (neuro)vascular injury appears to be responsible for this effect ($p<0.01$). Especially in the period directly following injury, the blood circulation in fracture fragments can be very delicate and, if compromised, this can cause a nonunion[31]. When long venous grafts are used to replace segments of damaged vessels, many vascular branches that would have supplied the soft tissue, periosteum, and bone in the region of the fracture are removed[33]. The prospective study of Chow et al. showed no significant relation between associated soft tissue injury and nonunion, though only 11% of their fractures were associated with neurovascular injury (30% in our series)[29]. Their relatively low rate of neurovascular injuries and smaller study group might explain why no significant relation was found between associated soft tissue injury and nonunion.

Replantation was a risk factor for the development of malunion in our series, as has been reported in previous studies[24,33]. This can be explained by the mode of injury (mostly by saw and crush injuries) which causes extensive bony injuries which preclude proper anatomical reduction. Moreover, the osteosynthesis that is used has to meet stringent requirements because of the bony instability and the need for early postoperative mobilization. The quality of osteosynthesis can be negatively influenced by the pressure on time in replantation procedures[24,33]. External fixation, which was used for comminuted intra-articular fractures and complicated contaminated fractures with skin and bone loss, was found to be significantly correlated with the development of malunion. Although some studies of external fixation report a high incidence of malunion[6,23], others report good results[34-37]. The extent of injury and the great instability which is inherent to the kinds of fractures which are treated by external fixation, sometimes render anatomical reconstruction impossible. Also, since the proper use of an external fixation is technically challenging, an optimal treatment result cannot always be expected in a teaching hospital. Of our group of conservatively treated fractures, six resulted in deviation and one in nonunion.

Osteosynthesis of concomitant, more severe fractures prohibited proper attention and treatment of these fractures, which, in retrospect did require osteosynthesis.

In conclusion, despite the relatively high number of severe injuries in our series, the healing of phalangeal fractures did not seem to be worse than in other series. We would like to emphasize the importance of maintaining the fragile fracture vascularization. Finally, the use of cancellous bone graft at an early stage is strongly advised when there is bone loss.

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Functional outcome after surgical treatment of phalangeal fractures in severely injured hands

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Abstract
We assessed functional results after treatment of phalangeal fractures in severely injured hands. Our aim was to quantify digital functional loss with (combinations of) risk factors of unsatisfactory function. Patients who had multiple phalangeal fractures necessitating operation in a 10-year time period were tested, using measurements of total active movement.
Seventy-eight patients with 228 phalangeal fractures were available for follow-up. In 88 fingers, the fractures ended in amputation and were excluded from the study. In the resulting 140 fractures, 74 (53%) had a good result (movement $>180^0$ for fingers 2-5, and $>98^0$ for the thumb), and 66 (47%) in an unsatisfactory result. Associated soft tissue injury, level of injury, and arthrodesis were risk factors for diminished function.
Intra-articular fractures and multiple fractures within the same finger predisposed to arthrodesis. Despite the extensive and severe injuries, more than half had good results, which is comparable with reports describing hand injuries with less extensive trauma.

Introduction
Healing of phalangeal fractures is associated with specific problems.
Bony healing can be complicated by nonunion, malunion, and infection.
Limited function may persist after the fracture has healed. After operation of phalangeal fractures, unsatisfactory functional results develop in 0 - 69% of fingers, although various definitions of unsatisfactory results were used in the studies[1-11]. In some studies, metacarpal fractures were also included and severity and extent of injury differed greatly[2,5,10,11]. Comminution of the fracture, level of injury, intra-articular fracture, operative dissection, rigidity of fixation, age, and associated soft tissue injury all give worse results functionally after a phalangeal fracture[1,2,5,8,10-13]. In severe hand injuries, with multiple phalangeal fractures that necessitate operation on the same hand or finger, various risk factors for functional impairment are present simultaneously. It is likely that functional recovery of a finger in such a hand is even worse.

As we encountered a number of severely injured hands in our clinic, we did a retrospective study to assess the functional results after surgical treatment of multiple phalangeal fractures in severely injured hands. The impact of risk factors and the resulting loss of movement were also evaluated.

Patients and methods
All patients with multiple phalangeal fractures in the same hand who were operated on at the Academical Hospital Rotterdam, Dijkzigt (currently Erasmus Medical Centre), during a 10 year period (July 1987--July 1997), were contacted. The minimum follow-up was two years. Results of osteosynthesis of phalangeal fractures in our clinic have been described previously[14]. In that study, a wider time frame was used, single phalangeal fractures were also included, and no functional evaluation was made[14].

A total of 112 patients matched the inclusion criteria, a total of 334 phalangeal fractures being operated on at our clinic. Seventy-eight patients (70%), with 228 fractures were available for testing, a mean of 2.9 phalangeal fractures/patient (range 2 to 7). The patients that did not participate in our study (34/112) had a comparable distribution of fractures as the patients that did participate, differences in distribution between groups not exceeding 2-3%. Mean age was 35 years (range 9 to 74). Mean follow-up was 7.4 years (range 2.3 to 11.6).

Of all patients who participated in the present study, we studied records and radiographs of the injured hand, and functional recovery of the fingers was tested and expressed in degrees of total active movement.
This was calculated as the sum of ranges of active movement of the metacarpo-phalangeal and interphalangeal joints, measured with an electronic goniometer (Greenleaf Medical Systems, Palo Alto, USA). Results from testing of fingers of the uninjured and opposite hand served as controls. A good result was defined when the total active movement was more than or equal to 180^0 for fingers 2-5, or more than or equal to 98^0 for the thumb. A lesser range was regarded as unsatisfactory.

Records were investigated for type of injury, presence of associated soft tissue injury (tendon injury or neurovascular injury), details of operations, and follow-up. Radiographs were studied for geometry of fractures, location of fractures, osteosynthesis used, consolidation, reduction achieved, and site of amputation. Fingers in which the amputation was proximal to the distal interphalangeal (DIP) joint that were not replanted, were excluded. Amputations at the uncuinate process of the distal phalanx, in which function of the DIP joint was intact and could be measured, were included in the study. Replanted fingers were also included. Each patient took part in a comparable program of treatment.

For statistical analysis we used ANOVA, using individual patients as subjects. Probabilities of less than 0.05 were considered significant.

Results
The most common mode of injury was crush, 103 fractures (45%). Most fractures were comminuted, 152 fractures (67%), and 121 fractures (53%) were intra-articular. Almost all were complicated and in 172 (75%) of fractures there was appreciable associated soft tissue injury: 121 (53%) of fractures had unilateral or bilateral neurovascular injury, 108 (47%) had flexor tendon injury, and 150 (66%) had injuries to the extensor tendon.

Most fractures were treated operatively; in 28 fractures (12%) of fractures there was a another, minor, stable fracture that was treated conservatively.

K-wires or interosseous wires were used most often (Table 1). There were 51 arthrodeses (22%). Thirty-two amputations were replanted (16 subtotal and 16 total amputations). In total 88 fractured fingers (39%) had either a primary amputation that could not be replanted, or such extensive injury that salvage of (part of) the finger was not possible. In total, therefore, 140 fractures in 70 patients were evaluated. The distribution of fractures is shown in Figure 1, and combinations of fractures in Table 2.

A total of 74 (53%) of non-amputated fractures had a good result, 66 (47%) had unsatisfactory results. For fingers 2-5, the level of injury ($p<0.05$), presence of associated soft tissue injury ($p<0.05$), and arthrodesis ($p<0.0001$) influenced function of the fingers significantly. In Table 3 the resulting loss in function and the percentage of good results is shown for the combination of these variables.

Intra-articular fractures predisposed for arthrodesis ($p<0.001$), as did the occurrence of multiple phalangeal fractures within the same finger ($p = 0.003$). For the thumb, only presence of an arthrodesis proved to be significant for function ($p<0.01$), probably as a result of small numbers.

Nonunion, malunion, infection, geometry of fractures, type of osteosynthesis used, total number of fractures, number of fractured fingers, and age, had no significant effect on function (as expressed in total active movement) in this series.

***Table 1:**. Types of fractures and osteosynthesis used*

	K-wire or inter-osseous wire	Lag screw	External fixation	Plate and screws	Ampu-tation	Con-serva-tive	Total frac-tures*
Comminutive	58	7	10	5	71	12	152
Transverse	8	0	2**	0	17	3	30
Oblique or spiral	8	2	0	2	8	5	23
Avulsion	9	2	0	0	1	7	18
Other	3	1	0	0	0	1	5
Total*	**85**	**12**	**10**	**7**	**97*****	**28**	**228**

* More than one type of osteosynthesis was used in some fractures.

** In two transverse fractures, external traction was used.

*** In nine cases, amputation was at the level of the uncuinate process of the distal phalanx and the function of the DIP joint could be measured. These fractures were included in the analysis.

***Figure 1:** Distribution of fractures in the phalanges.*

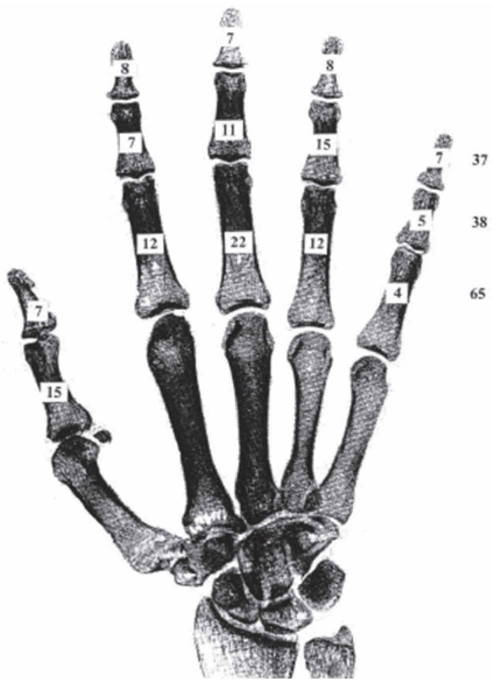

Table 2: Combinations of fractures in patients. Fractures that led to amputation are not included.

No. of patients	No. of proximal phalangeal fractures (digits 1-5)	No. of middle phalangeal fractures (digits 2-5)	No. of distal phalangeal fractures (digits 1-5)
11*	1	0	0
10	0	1	1
9	2	0	0
6	1	0	1
6*	0	1	0
5*	0	0	1
4	1	1	0
4	1	1	1
2	3	0	0
2	0	2	0
1	3	0	2
1	3	1	0
1	3	0	1
1	2	1	1
1	2	1	0
1	2	0	1
5	Other combinations of fractures		

* *In some of these cases, accompanying fractures led to amputation and were not included.*

Discussion

This study focused on severely injured hands, with several phalangeal fractures and extensive soft tissue injury within the same hand, that necessitated operation.

There is no uniform method of assessing the results of digital fractures of the hand[11]. We used total active movement of more than 180^0 for fingers 2-5 and more than 98^0 for the thumb to define a good result in accordance with most studies[1, 3-7,11]. Some studies define a total active movement of less than 180^0 for fingers 2-5 as poor[2-4,6-10] other studies make a distinction between poor (lesser than 130^0-150^0) and fair (between 130^0-150^0 and 180^0)[1,5,11], and sometimes fair is used for a total active movement between 180^0 and 210^0-220^0 [2,8-10]. We have decided to define a total active movement of less than 180^0 as unsatisfactory, to avoid conflicting definitions. Less than 180^0 for fingers 2-5, and 98^0 for the thumb, indicates that digital function is seriously impeded, although the finger can be useful in pinching, grasping, and helping function of the hand[1].

In our series of phalangeal fractures of which three quarters had associated injuries, over half had a good result, compared with 31%-71% good results with 28%-43% associated injuries in other published series, when extrapolating our outcome definitions[1,2,5,10,11]. However, other series of fractures of the hand are not easy to compare, because of their different inclusion criteria. Replanted fingers were not included in their analyses, whereas in our series 32 fingers were replanted.

Comminution of the fracture, level of injury, associated soft tissue injury, intra-articular fracture, operative dissection, rigidity of fixation, and age have been described as poor prognostic factors for the functional end result of fingers and hand after phalangeal fractures[1,2,5,8,11-13]. We could not study operative dissection and rigidity of fixation because our study was retrospective.

We found that comminution of the fracture had no appreciable effect on function of the fingers, as expressed by total active movement. Barton found that there was no difference in function of the fingers between comminuted fractures and non-comminuted fractures, as expressed by patients' or surgeons' satisfaction[15]. In other series, comminuted fractures had significantly worse functional results[2,10,11]. However, the intervariable correlation between comminuted fracture, associated soft tissue injury, and (indication for) operation were not clarified in these studies. Although comminution had no influence on function of the fingers in our analysis, we must emphasize that 46% of comminuted fractures with severe associated soft tissue injury required primary or secondary amputation and so were not included in our analysis.
As reported in other series, the level of injury is a prognostic factor for function of fingers[2,5]. Proximal phalangeal fractures have significantly worse function; adhesions that develop during healing in proximal structures are more likely to affect total function than more distal lesions. Associated soft tissue injury also affected function significantly. Deep flexor injury was the factor responsible for this effect ($p=0.02$), as reported in other studies[2,11,13].

Strickland et al. found that older age predisposed to worse functional results after phalangeal fractures[12]. When we used Strickland's criteria (comparison with 'normal' function: 260^0 for fingers and 140^0 for thumbs), aging was a significant predictor of unsatisfactory outcome ($p<0.01$) in our series as well.

Table 3 shows the combined effect and impact of different risk factors. Although standard deviations are high, it is clear that presence of an arthrodesis has the greatest effect on the functional result of an injured finger (on average 61^{0} functional loss), followed by level of injury (31^{0} functional loss), and associated injury (23^{0} functional loss). Of course, as every mechanism of fracture is unique, the numbers in this table cannot be extrapolated, and only give a rough approximation of the loss of function after any combination of fracture and risk factors.

In conclusion, despite the extensive and severe hand injuries that we studied, more than half gave good results, which compares well with other reports of the results of hand injuries with less extensive damage.
We assessed the average functional loss in terms of total active movement after surgical treatment of phalangeal fractures, for combinations of risk factors: arthrodesis, level of injury, and associated injury; to our knowledge, this has not been described before.

Table 3: *For fingers 2-5, average functional loss of total active movement (MCP + PIP + DIP) of affected fingers in severely injured hands compared with the uninjured fingers of the other hand, and percentage of good results in each category (total active movement more than 180^{0}).*

Phalanx	**No associated injury**		**Associated injury**	
	Mean functional loss ^{0} (SD)	Percentage of good results	Mean functional loss ^{0} (SD)	Percentage of good results
Without arthrodesis				
Proximal	72 (58)	67%	93 (51)	55%
Middle	32 (20)	75%	59 (27)	73%
Distal	0 (10)	100%	54 (61)	77%
With arthrodesis				
Proximal	131 (14)	0%	160 (28)	0%
Middle	112 (35)	20%	120 (49)	22%
Distal	76 (27)	43%	76 (13)	75%

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Impairment and disability following severe hand injuries with multiple phalangeal fractures

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Abstract
Upper-extremitiy impairment evaluation is performed mostly by using guidelines provided by the American Medical Association (AMA). Recently, subjective disability tests, as the Disability of the Arm, Shoulder and Hand (DASH) questionnaire, have been developed that appreciate the limitations patients experience in everyday life. In this study, the correlation between impairment and disability was assessed after treatment for severe hand injuries with multiple phalangeal fractures, with adjustment for comorbidity and follow-up duration.
The functional recovery of patients suffering severe hand trauma was evaluated using AMA impairment rating tests and DASH disability questionnaire scores.
Seventy-eight patients with 228 phalangeal fractures were available for testing, with a mean follow-up of 7.5 years. No statistically significant correlation existed between the AMA impairment ratings for the hand and the DASH module scores. There were weak correlations between the AMA impairment ratings for the arm and total body and the DASH module 'function' scores.
The lack of a strong correlation emphasizes the clear distinction between impairment and disability. The inclusion of disability outcome measures in the evaluation of hand trauma regimens, might help to expand the clinician's view to more individualized, activity-of-daily-living-oriented treatment regimens.

Introduction
For evaluation of hand function after (treatment of) hand trauma, objective parameters usually are used. Examples are measurements of strength (key, pinch, grip), sensibility (two-point discrimination, monofilament test), mobility (active and passive range of motion, pulp-to-palm distance), and function[1-4]. In the validated evaluation of the American Medical Association (AMA), according to *Guides to the Evaluation of Permanent Impairment*, objective parameters are combined, resulting in one impairment score for hand function, arm function, and total function[5,6]. Patients' perceptions of outcome or accomplishments in activities of daily living (ADL) were not measured in a standardized way until recently.

Patient-related and subjective factors severely affect hand function and have a marked influence on the length of time off work[7]. Therefore, a reliable and validated subjective outcome measurement might contribute to improvement of treatment regimens and rehabilitation programs or comparison of outcomes between different patient populations. Various subjective hand function tests have been developed, such as the patient evaluation measure, the hand function score, the standard health assessment questionnaire, the Michigan Hand Outcomes Questionnaire, and others[3,7,8-10]. No tests were performed to look for a correlation between these subjective hand function tests and the AMA impairment ratings.

In the Disabilities of the Arm, Shoulder, and Hand (DASH) Questionnaire, the subjective outcome parameters are standardized in a questionnaire, resulting in a limited number of scores (for function, work, and sports)[11]. This questionnaire is gaining popularity and designed to be a brief, self-administered measure of symptoms and functional status, with a focus on physical function, to be used by clinicians in daily practice and as a research tool[12]. The questionnaire still has to be validated for use in different areas. In a previous study in our department, a weak correlation (correlation coefficient: 0.3-0.4) was found between AMA impairment ratings and DASH scores, 6 months after hand trauma[13].

In the current study we investigated a group of patients who suffered more severe hand injuries, with multiple phalangeal fractures, and with a longer follow-up period. We hypothesized a stronger correlation between AMA impairment rating and DASH disability scores, thereby possibly reinforcing the clinical use of the DASH questionnaire.

Patients and methods

We contacted patients who had suffered multiple phalangeal fractures within the same hand and were treated surgically in the Academic Hospital Rotterdam, Dijkzigt (currently Erasmus Medical Centre), during a 10-year period (July 1987 to July 1997). The minimum follow-up was 2 years. The functional results of this group, using total active motion measurements, have been described previously[14].

The responding patients in the present study were evaluated by an independent physician (i.e. not a member of the team of treating physicians), who tested functional hand recovery by using the AMA guidelines.
The written DASH follow-up questionnaires were completed by the patients.
The actual ADL testing was not performed by the treating physician.
The measurements needed for assessment according to the AMA guidelines were performed using an evaluation system (EVAL hand and upper extremity evaluation system, Greenleaf Medical Systems, Palo Alto, CA). This program adheres to the AMA guidelines and calculates a percentage of impairment using contralateral, uninjured hand data as normative in the evaluation of permanent impairment. In the calculation for AMA arm impairment and total body impairment, pinch grip and grip strength were measured and included. All other body and joint functions (including wrist, elbow, shoulder) were considered normal for calculation purposes.

All patients also were asked to fill in the DASH follow-up questionnaire (version 2), which was translated into Dutch and validated at our department, according to the criteria of the Institute for Work & Health and the American Academy of Orthopedic Surgeons[15].

The DASH questionnaire includes a current health assessment and the DASH module. The health assessment concerns comorbidity, consisting of 14 questions relating to problems, treatment, and impairment of concurrent systemic diseases (e.g. cardiovascular disease, rheumatoid arthritis). This comorbidity index score is scaled from 0 (no comorbidities) to 100 (highest level of comorbidities). The DASH module consists of 3 parts. The functional symptoms section consists of 30 questions relating to functional activities and symptoms; the optional sport/music section module consists of 4 questions relating to hand function in sports or music activities; the optional work section module consists of 4 questions relating to hand function in specific job-required activities. A 5 point-scale is used for responses. The final summative score is converted to a percentage-scale, with 0 reflecting no disability (good function) and 100 reflecting major disability.

A statistical analysis was performed using ordinary Pearson correlation analysis and multiple linear regression analysis. In the latter analysis we estimated partial correlation coefficients between DASH and AMA, with adjustment for covariables comorbidity index and follow-up duration. The partial correlation is a measure for the strength of the linear relationship between DASH and AMA, after controlling for the effects of comorbidity index and follow-up duration. Statistical significance was defined as a p-value of less than .05.

The study was approved by our institutional medical ethical committee. Informed consent was obtained from all patients.

Results

Between July 1987 and July 1997, 112 patients matching the inclusion criteria with a total of 334 phalangeal fractures were identified. Seventy-eight patients (70%), with 228 fractures were available for testing, with an average of 3 phalangeal fractures (range 2-7) per patient. Mean age at trauma was 35 years (median 32 y; SD 15 y; range 9-74 y). The mean follow-up period was 7.5 years (median 8.1 y; SD 2.8 y; range 2.3-11.6 y).
The distribution of the fractures in the nonrespondent group was comparable with the fractures in the respondent group, differences in distribution between groups did not exceed 2 to 3%.

Table 1: *Statistical analysis of correlation between AMA impairment ratings, DASH module scores, comorbidity index, and follow-up duration. In brackets, the scores are shown that are corrected for comorbidity index and follow-up duration.*

DASH module		AMA impairment rating			Comorbid-ity index	Follow-up time
		Hand	**Arm**	**Total body**		
Function	Partial correlation	0.09 (0.14)	0.30 (0.35)	0.30 (0.34)	0.29	-0.17
	Significance (2-tailed)	0.42 (0.24)	0.007* (0.002*)	0.01* (0.003*)	0.01*	0.14
Sports/ Music	Partial correlation	-0.20 (-0.21)	-0.15 (-0.16)	-0.16 (-0.17)	-0.62	0.06
	Significance (2-tailed)	0.09 (0.07)	0.19 (0.17)	0.16 (0.15)	0.60	0.64
Work	Partial correlation	-0.01 (0.03)	0.20 (0.24)	0.19 (0.23)	0.34	-0.13
	Significance (2-tailed)	0.96 (0.79)	0.09 (0.045*)	0.10 (0.051)	0.003*	0.26

**) Significant*

The mean AMA impairment rating for the hand was 27 (median 23; SD 16; range 3-66), for the arm was 35 (median 34; SD 19; range 3-94), and for the total body 21 (median 21; SD 12; range 2-57). The measurements of pinch grip and grip strength were included in the calculation of impairment rating for the arm and total body.

The mean DASH score for the function module was 11 (median 7; SD 15; range 0-77), for the sports/music optional module was 10 (median 0; SD 18; range 0-81), and for the work module was 9 (median 0; SD 16; range 0-81).

Results of statistical correlation analysis are shown in table 1. After correcting for comorbidity index and follow-up time, the partial correlations between the DASH modules scores and the AMA impairment ratings were slightly stronger than the ordinary Pearson correlation coefficient. There was no statistically significant correlation between the AMA impairment ratings for the hand and the DASH module scores. There were statistically significant weak correlations between the AMA impairment ratings for the arm and total body and the DASH module function scores (partial correlation coefficient 0.35 and 0.34 respectively; p=0.002 and p=0.003 respectively), as shown in figures 1 and 2. There was also a statistically significant correlation between the AMA impairment ratings for the arm and the DASH module work scores (partial correlation coefficient 0.24; p=0.045), as shown in figure 3.

Figure 1: *Scatter plot of the AMA impairment rating for the arm versus DASH module: function score.*

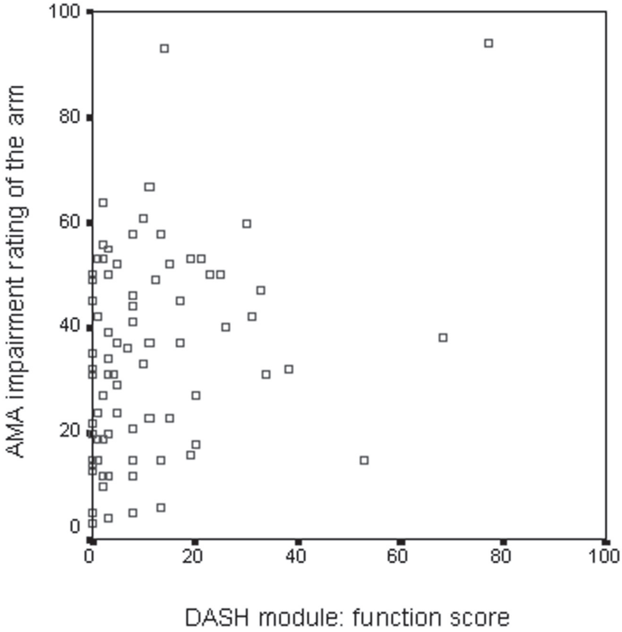


Figure 2: *Scatter plot of the AMA impairment rating for the total body versus DASH module: function score.*

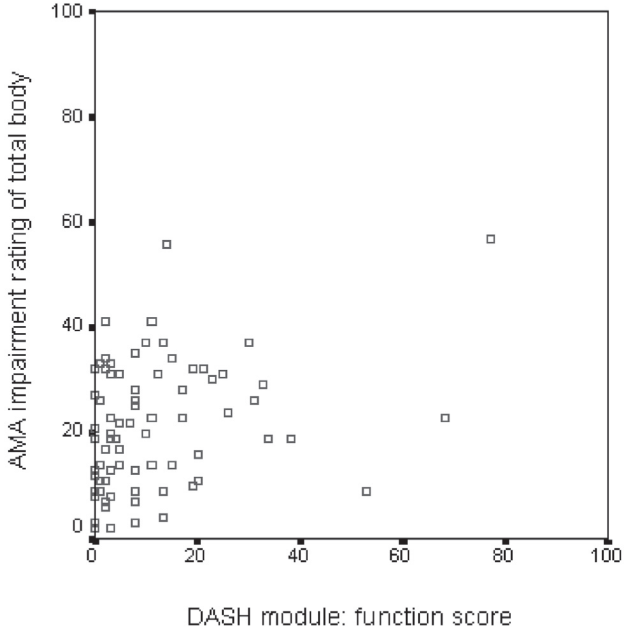
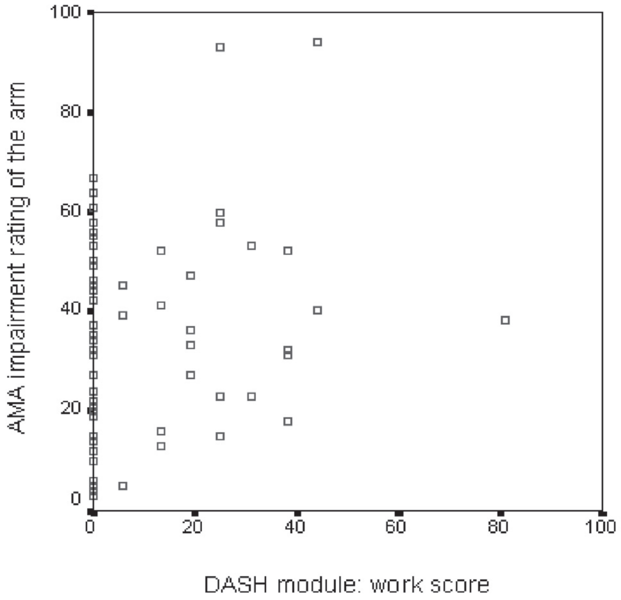


Figure 3: *Scatter plot of the AMA impairment rating for the arm versus DASH module: work score.*



The mean comorbidity index score was 3 (median 0; SD 6; range 0-24). Comorbidity proved to have a statistically significant correlation with DASH function and work modules (correlation coefficient 0.29 and 0.34 respectively; p=0.01 and p=0.003 respectively).
The follow-up time that elapsed between trauma and the time of testing did not correlate with impairment rates or disability scores, and did not notably modify the relationship between the impairment rates and disability scores.

Discussion
As clinicians, we are focused on objective impairment tests, as combined in AMA impairment ratings; measuring grades of motion of joints, strength, and stimulus thresholds. The patients' perspective however, is oriented towards restrictions and limitations in activities in daily life as a result of a trauma. This is scored in subjective disability outcome measurement tests, such as the DASH questionnaire.

"Although data provided only by the patient is somehow more subject to bias and measurement error than that recorded by a clinician or by a machine"[11], the lack of a (strong) correlation between the AMA impairment ratings and the DASH questionnaire as was found in this study, was not expected. It would seem logical that severity of impairment - as measured by a standardised hand function test according to the AMA definitions - would correlate with disability, as perceived by the patients and scored in the hand questionnaire (DASH). In a study by Mink van der Molen et al, a weak correlation (correlation coefficient: 0.3 - 0.4) was found between AMA impairment ratings and DASH scores, 6 months after hand trauma.
The weak correlation coefficients of about 0.3 - 0.4, as were also found in this study, mean that only 9 - 16 % of the variance of one variable is explained by its linear relationship with the other variable[13].

This low correlation is hypothesized to be caused by the many patient variables besides the injury itself. Factors like motivation, perceptions, beliefs, goals, mental status, patients' satisfaction, aesthetics, job, level of training, hobbies, welfare system, and workers' compensation make a subjective outcome measurement highly variable and may distort the correlation with an objective hand function test [2,3,7].

The long follow-up period (mean: 7.4 y) might provide an additional explanation. In this period, problems in functional activities slowly dissolve, as a result of everyday training and compensation mechanisms. Because usually only one hand is injured, the other healthy hand can compensate for the loss of function. The low DASH score reflects adaptations the patient has made in coping with his handicap in performing ADL tasks.
In the 6 months follow-up study of Mink van der Molen et al[13], the mean AMA impairment ratings for the hand, arm, and total body were 17, 25, and

15 respectively (measurements of pinch and grip strength were included in the calculations of the arm and total body AMA scores, leading to higher scores as compared with the hand). The mean DASH scores in the same study were 14 (function), 22 (sports/music), and 20 (work)[13]. In the current study with a longer follow-up, mean AMA impairment ratings for the hand, arm, and total body were higher, 27, 35, and 21 respectively; the mean DASH scores were relatively low: 11, 9, and 9 for the function, sports/music, and work module respectively. The findings in the current study, with higher AMA impairment ratings, and lower DASH scores when follow-up time is much longer, seem to underscore the hypothesis of compensation and adaptation during longer follow-up periods. Follow-up time however, proved to have no relationship in statistical analysis with DASH or AMA scores in this study. Possibly, the end points for compensation and adaptation have been attained in the period between 6 months follow-up (Mink van der Molen et al.[13]) and 2.3 years, which was the minimum follow-up time in our study.

Nevertheless, the lack of a (strong) correlation is also an outcome that emphasizes the differences between impairment and disability as separate entities. When looking for a correlation between disability measurements and impairment ratings as we did, the added value of subjective disability measurements might be overlooked. Apart from impairment of function, recovery is a product of good clinical and psychological judgement of the treating surgeon, extensive individualized rehabilitation programs, psychologic support, prosthetic care, and attention to and support in social contexts and jobs[16-25].

The inclusion of subjective disability scoring tests in the evaluation of treatment of hand trauma, might help to expand the focus to more individualized, more ADL-oriented treatment regimens. Goals of treatment have to be not only to decrease impairment ratings, but also to decrease disability scores.

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Quality control of metacarpal and phalangeal fracture management in a teaching hospital

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Abstract
In order to assess current practice of phalangeal and metacarpal fracture management in a teaching hospital, and identify improvement needs, a quality control study was performed.
In a 7 months period, all incoming fractures at the Accident and Emergency Unit (A&E Unit) were prospectively included. Fracture treating residents of Traumatology, Orthopedic Surgery, and Plastic Surgery at the A&E Unit and at the Outpatient Clinic or Operating room were asked to classify the fractures and to record the treatment plan on standard forms. Experienced surgeons assessed the classification of fractures and compared treatment plans to protocol. Also results of treatment were scored.
In total 384/463 (83%) of diagnoses were correct and 410/463 (89%) of treatment plans were according to protocol, leading to 159/198 (80%) of properly healed fractures and 32 primary or secondary amputations. Operative treatment was adequate in 42/52 (81%) of cases.
The percentages of proper unions, correct diagnosis and treatment plans of phalangeal and metacarpal fractures admitted to the A&E Unit of our teaching hospital are comparable to literature. Additional training for hand fracture treating residents and strict supervision are suggested for improvement of care.

Introduction
Treatment of metacarpal and phalangeal fractures is non-operative including a relative short period of external stabilisation in most cases[1,2]. However, malunion, nonunion, and limited arc of motion following (treatment of) these fractures can lead to prolonged time off work, functional loss, and even disability[3-7].
In the Accident and Emergency Unit (A&E Unit) of teaching hospitals, these fractures are usually treated by emergency physicians or residents of the trauma, orthopaedic, or plastic surgery department. At several points in the course of treatment, security checks by means of authorisation of treatment by senior staff surgeons should be implemented in the teaching environment.
In order to evaluate the current practice of treatment of metacarpal and phalangeal fractures in a university teaching hospital, and to identify improvement needs, a quality control study was performed.

Patients and methods
In a 7 month period, from September 2005 to April 2006, all patients visiting the A&E Unit of a teaching hospital, with a phalangeal or metacarpal fracture which was less than 2 weeks old, were prospectively included in this study. The attending emergency physician or resident treated the incoming patients. Five days a week incoming fractures were treated by the attending emergency physician or resident of the Trauma department; two days a week fractures were treated by an Orthopaedic resident.

Plastic Surgery residents treated fractures on the A&E Unit only when consulted by one of above mentioned physicians. Reasons for consultation were: extensive injuries including (sub)total amputations, complicated fracture(s), and fractures associated with a severe soft tissue injury (i.e. tendon and/or neurovascular injury).
Patients were treated conservatively at the A&E Unit or operated upon. When conservative treatment was initiated in the A&E Unit, patients were usually followed-up at the outpatient clinic of Traumatology or Orthopaedics (dependent on treating physician on A&E Unit: Traumatology 5 days/week; Orthopaedics 2 days/week) one week later.
Monday till Friday morning, all fracture radiographs were screened by a consultant of the Trauma department, and treatment plan was altered when deemed necessary. Residents of Orthopaedics or Plastic Surgery on the A&E Unit were not regularly supervised. In the outpatient clinic or operating room of Traumatology, Orthopaedics, or Plastic Surgery, supervision by a senior staff member is always available.
A detailed protocol (see: appendix) for treatment of phalangeal and metacarpal fractures was present at the A&E Unit and was distributed to all participating residents. This protocol was approved by the senior staff members of Traumatology, Orthopaedics, and Plastic Surgery.
Data concerning occupation, dexterity, mode of injury, fracture diagnosis, and treatment plan were gathered in the A&E Unit using a standard form. If the forms were not (completely) filled in, patients' records were studied to gather missing data. In the operating room or the outpatient clinic, data were gathered on fracture geometry, exact fracture localisation, and (changes of) treatment plans, using a second, other form.
Radiographs of fractures were classified by radiologists and checked by the senior authors, who are experienced surgeons. The anonymised primary radiographs of the A&E Unit, the outpatient clinic, or the osteosynthesis were presented to the senior authors, and scored at each consecutive moment of treatment. If necessary, the clinical data associated with the radiographs could be consulted when the treatment plan was evaluated. If there was no consensus between the three senior authors, the majority of votes were followed (i.e. two versus one). The senior authors were not the supervising physicians in the majority of cases.
Classification of fractures was not rigidly scored: caput or neck localisation, and oblique and spiral fracture geometry were both valid and could be used exchangeable. However, a wrong classification was scored, irrespective of outcome, if for instance intra-articular fractures were not appreciated as such, comminution of the fracture was not noticed, or insufficient description was noted, e.g. 'fracture third ray', without further elaboration. Treatment plans were compared to the protocol and checked by the senior authors.
A malunion was scored if more than 10 degrees of angulation was measured in a healed phalangeal fracture. Also a malunion was scored

if more than 10 degrees of angulation was measured in the second or third metacarpal, or more than 20 or 30 degrees in the fourth and fifth metacarpal respectively in a standard antero-posterior, or three-quarters oblique metacarpal radiograph. Shortening that was noticed by the senior authors on standard antero-posterior metacarpal X rays, was also scored as a malunion. Rotational deformities, when noticed in this radiological analysis, were also scored as a malunion. Minimum radiological follow-up for a malunion score was 6 weeks. A nonunion was scored if no bony callus was formed 6 months following the injury. In cases when the follow-up was not long enough for a definitive verdict, and a malunion or nonunion was most likely to ensue according to the senior authors, a 'possible malunion' or possible nonunion' was scored. Osteosynthesis was scored as inadequate when osteosynthesis material did not improve fracture stability (e.g. K-wire only nails the proximal fracture part), or when insufficient bony apposition (less than 50%), or insufficient reduction (i.e. $> 10^0$ of angulation for phalangeal and second/third metacarpal fractures; $> 20^0$ and $> 30^0$ angulation for metacarpal four and five respectively) was realized. Statistical analysis between groups was performed using Chi-square testing.

Results

In the aforementioned period, a total of 182 patients (131 men and 51 women) were seen at the A&E Unit with in total 230 phalangeal or metacarpal fractures, on average 1.26 fracture per patient (range 1 to 7). In an additional 14 cases, a fracture was presumed at the A&E Unit or the Outpatient Clinic, but could not be objectified by the senior authors, when checking the radiographs. Mean age at trauma was 37 years (median 33; SD 15; range 12-75). Distribution of fractures is depicted in table 1.

Table 1: *Distribution of fractures over phalanges. Presumed fractures were classified as such at the A&E Unit or outpatient clinic, but could not be recognised at revision of radiographs.*

		Phalanx				
Finger	**MC**	**Proximal**	**Mid**	**Distal**	**Presumed**	**Total**
1	5	9	-	11	2	27
2	4	8	7	11	3	33
3	12	11	7	18	3	51
4	31	7	6	18	3	65
5	40	9	7	9	3	68
Total	92	44	27	67	14	244

Two patients were not included in the study: one patient had a pathological fracture caused by an enchondroma, the other withdrew himself from treatment in the A&E Unit.

Mean follow-up was 296 days (median 299 days, SD 61, range: 188-404). Serious associated injury was present in 58 fractured fingers (24%), consisting of 16 isolated extensor tendon injuries, one isolated neurovascular bundle injury, 35 subtotal amputations and six complete amputations. Eight fingers suffered a luxation of an interphalangeal joint, necessitating reduction, and 12 fingers had serious soft tissue injury to the terminal phalanx, including nail(bed) injury. Eight patients suffered serious associated hand injuries in the same hand as carpal fractures or luxations (5), complete ulnar collateral ligament rupture of the thumb (2), or compartment syndrome (1); six patients suffered serious associated injury as ulna fracture (1), shoulder luxation (1), contusion of thorax (1) or cerebrum (2), epidural hematoma (1).

In total 384/463 (83%) of diagnoses - diagnoses of the two separate forms combined, gathered at the A&E Unit and at the Outpatient clinic/Operating room - and 410/463 (89%) of treatment plans were according to protocol.

Of the 230 fractures, 32 were primarily (6) or secondarily (26) amputated. Of the remaining 198 fractures, 159 (or 80%) healed properly.

Osteosynthesis was accurate in 42/52 (81%) of cases. Distribution over the different specialties is depicted in table 2. Insufficient osteosynthesis (10/52) resulted in seven malunions and one possible malunion ($p<0.001$).

Specialism	Department: A&E Unit		Department: Operating room or Outpatient clinic		Treatment modality			Outcome		
	Diagnosis correct	Treatment plan correct	Diagnosis correct	Treatment plan correct	Operative treatment	Osteo-synthesis used in operation	Osteo-synthesis adequate	Ampu-tation	Proper union (con-servative)	Proper union (operative)
Traumatology	87/110 (79 %)	90/110 (82 %)	68/91 (75 %)	76/91 (84 %)	20/102 (20%)	14/20 (70 %)	6/14 (43 %)	4/102 (4 %)	65/82 (79%)	9/16 (56%)
Orthopaedic surgery	54/60 (90%)	53/60 (88 %)	47/59 (80 %)	51/59 (86 %)	8/56 (14 %)	7/8 (88 %)	6/7 (86 %)	0/56 (0 %)	39/48 (81%)	6/8 (75)
Plastic surgery	66/74 (89 %)	73/74 (99 %)	62/69 (90 %)	68/69 (99 %)	67/72 (93 %)	31/67 (46 %)	30/31 (97 %)	28/72 (39 %)	5/5 (100%)	35/39 (90%)
Total	207/244 (85 %)	216/244 (89 %)	178/219[1] (81 %)	195/219[1] (89 %)	95/230[2] (41 %)	52/95 (55 %)	42/52 (81 %)	32/230[2] (14 %)	109/135 (81%)	50/63 (79%)

Table 2: *Distribution of diagnosis and treatment plans over specialisms. Some patients were only seen and treated at the A&E Unit. Non-properly united fractures suffered malunion (36) or nonunion (3).*

1) Twenty-five patients were only seen and treated at the A&E Unit
2) Fourteen presumed fractures were excluded in outcome figures

There was no significant difference in percentage of correct diagnoses or treatment plans between residents of Traumatology and Orthopaedics. The number of osteosyntheses was considered to low for statistical analysis. Since Plastic Surgery usually treated a different subset of patients, no comparison was made with Traumatology or Orthopaedics.
Thirty-seven diagnoses of the A&E Unit were incorrect. Of these, 21 cases were correctly diagnosed secondarily at the Outpatient clinic/Operating room (21/31 or 68%; six patients were only seen at the A&E Unit). Similarly, in 28 cases, the treatment plans at the A&E Unit were incorrect. Of these, in three cases a correct treatment plan was made secondarily at the Outpatient clinic/Operating room (3/24 or 13%; four patients were only seen at the A&E Unit, table 3). Misdiagnosis was scored mostly for incorrect classification; mismanagement was scored most frequently for insufficient reduction and conservative treatment instead of osteosynthesis (table 4).
In table 5, a description is provided of malunions (28) and possible malunions (8). Three fractures ended in nonunion (2) or possible nonunion (1).

Table 3: *Correction of diagnosis and/or treatment plan at Outpatient clinic or Operating room.*

Specialism	Correct secondary diagnosis after incorrect primary diagnosis (%)	Correct secondary treatment plan after incorrect primary treatment plan (%)
Traumatology	12/17 [1] (71 %)	3/16 [2] (19 %)
Orthopaedic surgery	3/6 (50 %)	0/7 (0 %)
Plastic surgery	6/8 (75 %)	0/1 (0 %)
Total	21/31 [1] (68 %)	3/24 [2] (13 %)

[1)] Six patients with an incorrect diagnosis were only seen at the A&E Unit; hence correction of diagnosis could not be performed and patients are not included in this table.
[2)] Four patients with an incorrect treatment plan were only seen at the A&E Unit; hence correction of treatment plan could not be performed and patients are not included in this table.

		Misdiagnosis					Mismanagement		
	Specialism	Fracture missed	Incorrect classification	Incorrect localisation	Insufficient description	No fracture present	Inadequate reduction	Osteosynthesis required	Follow-up indicated
A&E Unit	**Traumatology**	4	1	6	7	7	14	7	4
	Orthopaedic surgery	2				4	8	4	
	Plastic surgery	2	1	3		2	1		
	Total	**8**	**2**	**9**	**7**	**13**	**23**	**11**	**4**
Outpatient clinic or Operating room	**Traumatology**	5	9	6		2	9	9	
	Orthopaedic surgery	3	5	4		1	6	6	
	Plastic surgery	2	4	3			1		
	Total	**10**	**18**	**13**		**3**	**16**	**15**	

Table 4: *Motivations of misdiagnosis and mismanagement at the A&E Unit.*

__Table 5:__ Description of malunions and possible malunions.

	Description malunion				
Specialism	**Deviated phalanx**	**Shortened metacarpal**	**Angulated metacarpal**	**Intra-articular dislocation**	**Other**
Traumatology	7 [1]	5	6 [2]	4 [1]	
Orthopaedic surgery	1	3	5 [3]	1	1
Plastic surgery	2			1 [1]	
Total	10 [1]	8	11 [5]	6 [2]	1

1,2,3,5) Number of fractures in which a malunion was expected but follow-up was to short for confirmation, i.e. 'possible malunion'.

Radiology reports were deemed accurate in 223/244 or 91% of cases. Misdiagnosis of radiology was due to missed fractures (8/244; 3%), incorrect localisation (5/244; 2%), incorrect classification (5/244; 2%), missing reports (2/244; 1%), and no fracture present (1/244; 0.4%).

Discussion

Training of residents and registrars in teaching hospitals is a delicate balance between strict supervision and developing autonomy, whereby patient care should be performed at high level. Especially in hand surgery, where margins are small, training poses a challenge for the supervising surgeons. Therefore, regular and standardized audits are essential to assess quality of everyday practice[8].

The malunion rate of 18% (36 of 198 non-amputated fractures) - including 8 possible malunions -, the nonunion rate of 1%, and inadequate osteosynthesis rate of 19% are in concordance with other reports.

In a study by Pun, malunion rate was not mentioned, nonunion rate was 2% (6/277) and 9% of osteosynthesis was deemed inadequate (10 of 109 operatively treated fractures). However, for inadequate osteosynthesis the term 'mechanical failure of osteosynthesis' was used in Pun's study, which might imply less strict criteria as were used in our study. In Pun's study, only fractures occurring in the distal one quarter of the metacarpal or the proximal and middle phalanges were included; furthermore, avulsion fractures from the joint margins and any fracture dislocations of the digits were excluded[1]. In a study by Ip, malunion rate was 20%, nonunion rate was 3%, while operative fixation was considered 'non-rigid' in 32% of operatively treated fractures (139 of 438). In the study of Ip, a similar selection was used as in the study of Pun.

Fractures necessitating revascularization or replantation, or fracture-dislocation with volar plate injury were excluded in Ip's study[9]. Definition of malunion in Ip's study is less strict, accepting 20^0 of sagittal angulation in the juxta-articular region, and 45^0 degrees of angulation in the metaphysis of the 5^{th} metacarpal. The issue of treating surgeons (residents or consultants) is not addressed in the studies of Pun and Ip[9,1].

Most of malunions in our study were the result of conservatively treated metacarpal fractures (table 5): either more angulation in metacarpal neck of the fourth and fifth digit was allowed than was agreed upon in the protocol, or fractures with shortening were left untreated. Either more attention should be drawn towards correct reduction and/or osteosynthesis of these relatively easy avoidable complications, or our protocol is too strict in these instances. For the reasons of this study, strict protocolised treatment was prescribed. In everyday practise however, patients' factors (e.g. age, occupation, compliance) are of course weighed as well in defining the treatment plan. Therefore, the malunions in our study will probably not all have functional implications.

There is discussion about the amount of acceptable angulation in fifth metacarpal neck fractures[10-12]. Although the biomechanical study of Ali predicts functional limitations in boxers' fractures exceeding 30^0 of angulation, clinical studies do not seem to support these data[10-12].
As for acceptable metacarpal angulation, our protocol can be less strict.
For the case of metacarpal shortening, a cadaver study was done by Strauch, in which was shown that for each 2 mm increment of metacarpal shortening, an average extensor lag of 7^0 was produced at the MCP joint[13].
Vahey's comparable study - albeit in proximal phalangeal shortening - showed that the extrinsic extensor tendon has a reserve of 2-6 mm, beyond which 12^0 of extensor lag/mm shortening occurred at the PIP joint[14].
The intrinsic system of interossei and lumbricals can overcome some extensor lag, although at the expense of altered dynamics and balance in the extensor apparatus[14,15]. In order to avoid these functional limitations, our guidelines scoring shortening as a malunion remain unchanged. The amount of metacarpal shortening was not measured in a standardised manner in this study, since we lacked contra-lateral data of metacarpal length or 'pre-fracture' radiographs.

The relatively high rates of phalangeal deviation and intra-articular dislocations in our series need to be addressed, since scissoring of fingers and early arthrosis of interphalangeal joints respectively can lead to serious functional impairment. Additional specific fracture training for residents and attention of supervising staff is warranted.

The overall correct diagnosis rate of 83% and correct treatment plan rate of 89% of the A&E Unit is comparable to Davis' A&E Unit study.

In that study 82% of diagnosis were correct, although only radiologists reports were taken into account. The rate of satisfactory treatment was 75%; unfortunately no clear definitions were presented for 'satisfactory' alignment or reduction, which makes comparison difficult[16]. Most of the misdiagnoses in our series are due to inattentiveness (missed fracture, incorrect localisation) and insufficient experience (incorrect classification). When protocol would have been followed more strictly, practically all incorrect treatment plans could have been avoided. Execution of treatment (i.e. proper reduction and osteosynthesis) is a matter of experience, skill and routinely performing control radiographs during operation or following reduction.

Still, in every other high-professional working environment, 17% of incorrect diagnoses and 11% of incorrect treatment plans (A&E Unit and Outpatient clinic/Operating room combined) would be unacceptable and unworkable. More supervision might improve results[16-19].

In our hospital no special supplementary training is given to residents treating hand fractures, except for everyday practise. Residents of Plastic Surgery have an obligatory formal two days hand fracture training course, daily exposure to hand surgery, and three supervising designated hand surgery consultants. In order to improve quality of hand fracture care in our hospital, a structural hand fracture diagnosis and treatment (refreshment) course should be instituted for all residents involved in hand fractures.

This course should include: hand traumatology theory, knowledge of trauma mechanism and fracture dynamics, indications for surgical treatment, (functional) anatomy of the hand, and training in application of splints and splint techniques.

The operative treatment, with on average seven cases of osteosynthesis every month, should be concentrated in an appropriate guided training program for the residents. Additional to the subjects of the above mentioned course, this training program should include training in hand osteosynthesis techniques and theory.

In conclusion, the percentage of proper unions, correct diagnosis and treatment plans of phalangeal and metacarpal fractures admitted to the A&E Unit of our teaching hospital is comparable to literature. Additional training for hand fracture treating residents and strict supervision are suggested for improvement of care.

Appendix
Treatment protocol which was present at the A&E Unit and was distributed to all fracture treating physicians.

Treatment protocol phalangeal and metacarpal fractures

Phalangeal fractures
Conservative
Indications for conservative treatment are:
- Single avulsion fractures, transverse fractures or short oblique fractures (no spiraling)
- Extra-articular
- Undisplaced, stable at presentation. Displaced, stable after reduction
- Uncomplicated, no significant soft tissue injury (i.e. tendon and/or neurovascular injury)

Conservative treatment:
- Displaced fractures: reposition (loco regional anesthesia), followed by static splinting for three weeks (wrist: 20^0-30^0 extension; fingers: intrinsic plus position). Control X-ray in splint, two directions (proper alignment!).
- Oblique fractures of the phalangeal shaft (no spiraling): static splinting (see above) for 3 weeks.
- Other fractures: 'living splint' or 'buddy strapping' for 2-3 weeks with active mobilization.

Control X-ray after 1 week, two directions. When splinted following reposition, the X-rays are performed without changing the splint.

As soon as possible, or directly following treatment with splints, active mobilization exercises should be initiated. The first 6 weeks following the fracture, no stress should be applied.

Surgery
Indications for surgical treatment are one or more of the following:
- Dislocated fractures that cannot be reduced
- Not stable following reduction
- Intra-articular fractures
- Spiral fractures or comminutive fractures
- Oblique fractures with shortening
- Fractures with associated soft tissue injury (complicated fractures, association with tendon injury or neurovascular injury)
- Nonunion or malunion following conservative treatment.

Surgical treatment:
- Closed reduction and percutaneous osteosynthesis
- Open reduction and osteosynthesis
- Dynamic traction
- Debridement, repair of soft tissue injury

<u>Specific fractures</u>
- Mallet fracture: fracture of the base of the distal phalanx, dorsal side, caused by avulsion of the extensor apparatus insertion. This may either be treated by a short (hyper-) extension splint for the distal interphalangeal joint (Stack splint or Mallet splint) for 6 weeks, or be reduced and fixated by operative techniques. Consultation of hand surgeon is warranted. Rehabilitation following splinting by hand therapist. When the avulsed part comprises more than 1/3 of the (articular) base of the distal phalanx, surgical treatment is indicated.

Metacarpal fractures
Conservative
Indications for conservative treatment are:
- Single fractures: transverse or short oblique
- Stable following reduction
- No rotatory malalignment
- Angulation:
    - Second and third metacarpal: $< 10^0$ apex dorsal angulation
    - Fourth and fifth metacarpal shaft fractures: $< 20^0$ or 30^0 apex dorsal angulation respectively
- At least 50% apposition of fracture parts
- Uncomplicated, no significant associated soft tissue injury

Conservative treatment:
- Reduction (if necessary), splinting for 2-3 weeks.

Surgery
Indications for surgical therapy are one or more of the following:
- Spiral or oblique fractures with rotatory component
- Comminutive fractures
- Dislocated fractures
- Multiple fractures
- Intra-articular fractures
- Fractures with associated soft tissue injury (complicated fractures, association with tendon injury or neurovascular injury)
- Nonunion or malunion following conservative treatment.

Surgical treatment:
- Closed reduction and percutaneous osteosynthesis
- Open reduction and osteosynthesis
- Debridement, repair of soft tissue injury

Specific fractures:
- Bennett fracture: intra-articular single fracture with luxation of the first metacarpal base. Traction of the abductor pollicis longus muscle causes luxation of the first metacarpal base proximally. Surgical treatment.
- Rolando fracture: comminutive, intra-articular fracture of the first metacarpal base. Traction of the abductor pollicis longus muscle causes luxation of the first metacarpal base proximally. Surgical treatment.
- Reversed Bennett fracture: fracture of the fifth metacarpal base. Traction of the extensor carpi ulnaris muscle causes luxation of the fifth metacarpal base proximally. Surgical treatment.

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Consequences of phalangeal and metacarpal fractures in a teaching hospital: a prospective study

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Abstract
In order to objectify financial, personal and logistic impact of treatment of phalangeal and metacarpal fractures and identify opportunities for improvement, a prospective study was performed.
In a seven months period, patients with a phalangeal or metacarpal fracture attending the Accident and Emergency Unit (A&E Unit) of a university hospital, were included. Endpoints were: hospital costs, hospital visits, days in the hospital, number of operations, and period off work. Eighteen variables that possibly influenced outcome data were statistically tested.
One hundred and sixty-one patients with 214 phalangeal or metacarpal fractures were included in this study. On average, hospital costs were €1987 (range €193 to €23,205), patients visited the outpatient clinic seven times (range 1 to 98), hospital admission for operative treatment of phalangeal or metacarpal fractures lasted 3.6 days (range 0 to 17), for on average 1.5 operations (1 to 4), and people with paid employment lost 32 days of work (range 0 to 206) due to the injury. Ten out of 18 variables proved to have a statistical correlation with the endpoints.

Introduction
Hand injuries involving metacarpal and phalangeal fractures in an Accident and Emergency Unit (A&E Unit) are frequent, between 0.2 and 3% of all patients visiting the A&E Unit[1,2,14]. Although these injuries may appear relatively minor, impact of these injuries can be higher than commonly estimated. Besides impairment, these injuries may lead to a long period off work, high costs (e.g. hospital bills), multiple hospital visits and prolonged rehabilitation efforts[3-5].
A prospective study was performed, in order to objectify these sequelae and to identify influencing variables. This information might lead to more efficient use of resources and result in improvement of care.
In this study, hospital costs, period off work, and hospital visits in the course of treatment of phalangeal and metacarpal fractures are prospectively quantified in a teaching hospital in the Netherlands. A statistical analysis of variables influencing these outcome data was performed.

Patients and methods
From September 2005 to April 2006, all patients with a phalangeal or metacarpal fracture visiting the A&E Unit of a university hospital in the Netherlands, were prospectively included in this study. Patients with significant associated injuries that were not related to fingers or metacarpalia, or with fractures older than two weeks were excluded. Fractures at the A&E Unit were treated according to protocol by the attending emergency physician, a resident of the Trauma department (5 days a week), or a resident of the Orthopaedic surgery department (2 days a week). Residents of Plastic surgery treated fractures on the A&E Unit on a consultation basis in case of extensive injuries including (sub)total

amputations, open fracture(s), and significant associated soft tissue injury (i.e. tendon and/or neurovascular injury). The aforementioned protocol was present at the A&E Unit and was distributed to all participating residents. The protocol was approved by the senior staff members of Traumatology, Orthopaedics, and Plastic Surgery.
Following conservative or operative treatment, patients were usually invited for control visits at the outpatient clinic. Data concerning the patient, fracture(s), diagnosis, treatment plan, and outcome of osseous healing were prospectively gathered (table 1). Fracture treatment plans were gathered both at the A&E Unit and at the outpatient clinic (when applicable), leading to two fracture treatment plans per patient. Standard radiographs in two directions were made for each fracture and radiologic examination was expanded when deemed necessary. Treatment plans, and adequacy of treatment were checked and compared to protocol by a panel of the senior authors, who are experienced surgeons (Trauma surgeon, Orthopaedic surgeon, Plastic/Hand surgeon). Treatment was classified as inadequate when the fracture ended in a malunion or nonunion, or when an insufficient osteosynthesis was performed, irrespective of the outcome of treatment.

A malunion was scored if more than 10 degrees of angulation was measured in a healed phalangeal fracture. Also a malunion was scored if more than 10 degrees of angulation was measured in the second or third metacarpal, or more than 20 or 30 degrees in the fourth and fifth metacarpal respectively in a standard antero-posterior, or three-quarters oblique metacarpal radiograph. Shortening that was noticed by the senior authors on standard antero-posterior metacarpal X rays, was also scored as a malunion. Rotational deformities, when noticed in this radiological analysis, were also scored as a malunion. Minimum radiological follow-up for a malunion score was 6 weeks. If there was no consolidation or bony callus six months following the injury, a nonunion was scored. If radiological follow-up was too short for a conclusion, and a malunion or nonunion was expected to occur, a ‘probable malunion’ or ‘probable nonunion’ was scored. Osteosynthesis was scored as inadequate when osteosynthesis material did not improve fracture stability (e.g. K-wire only nailing the proximal fracture part), or when insufficient bony apposition (less than 50%), or insufficient reduction (i.e. $> 10^0$ of angulation for phalangeal and second/third metacarpal fractures; $> 20^0$ and $> 30^0$ angulation for fractures of metacarpal four and five respectively) was realized.

Table 1: *Variables and end points entered in statistical analysis*

Variables entered in statistical analysis	End points
• Age • Sex • Follow-up time • Type of work (blue/white collar) • Type of employment (employed/ self-employed) • Dominant hand trauma (yes/no) • Energy of trauma (low/high energy) • Circumstances of trauma (home-street/work/traffic) • Pre-existing impairment • Associated injury (none/extensor/ amputation/luxation/soft tissue terminal phalanx/other) • Operation (yes/no) • Number of fingers involved • Average number of fractures/finger • Number of amputated digits/patient • Intra-articular involvement • Number of inadequate osteosynthesis/patient • Number of malunions/patient • Number of incorrect treatment plans/patient	• Number of outpatient clinic visits • Days in the hospital (when operated) • Number of operations • Days off work (when employed) • Costs of treatment

The electronic/digital hospital information system was searched for the number of outpatient clinic visits and hospital days; the financial department was contacted for the hospital expenses covering the direct costs of treatment (i.e. A&E Unit visits, outpatient clinic visits, operation costs, costs for hospital care, etc.). In this study, only direct costs of treatment in the hospital were included (not first line medical care, transport, domestic help, and other medical care costs).

After a minimum follow-up of 6 months, all included patients were called upon and were asked for days off work following the injury. In part-time jobs, only the missed working days were accounted for.

Statistical analysis between groups was performed using multiple regression analysis (Poisson regression or Uni-Anova multiple regression when indicated). Variables that were tested as predictors of outcome parameters are listed in table 1, as are the outcome parameters.

Treating specialism (trauma surgery, orthopaedics, plastic surgery) was not entered as a variable due to differing patient groups and fracture characteristics. Probable malunions and nonunions were entered as malunions and nonunions.

Results

In the aforementioned period, a total of 161 patients (117 men and 44 women) with hand injuries were seen at the A&E Unit with in total 214 phalangeal or metacarpal fractures, on average 1.3 fractures per patient (median 1; SD 0.8; range 1-7). Distribution of fractures is depicted in table 2.

Table 2: *Distribution of fractures over phalanges.*

		Phalanx			
Finger	**MC**	**Proximal**	**Mid**	**Distal**	**Total**
1	4	7	0	11	22
2	3	8	7	10	28
3	12	11	7	18	48
4	27	6	6	18	57
5	36	8	6	9	59
Total	82	40	26	66	214

Mean age at trauma was 36 years (median 33; SD 15; range 12-75).
Sixty patients did not perform paid labour (60/161, or 37%) - i.e. were unemployed or students -, 55 patients were blue collar workers (55/161, or 34%), and 37 patients were white collar workers (37/161, or 23%).
In nine patients, data concerning occupation were missing. The dominant hand was injured in 84/152 (55%) of cases (in nine patients, dexterity was not recorded). Injuries occurred in a working environment in 38/156 (24%), in traffic in 12/156 (8%), or in other circumstances (106/156, or 68%; of five patients no place of trauma was recorded). Most injuries were low-energetic in nature (123/161, or 76%).

Significant associated injury was present in 57 fractured fingers (57/214, or 27%), consisting of 16 isolated extensor tendon injuries, 35 subtotal amputations and six complete amputations. Eight fingers suffered a dislocation of an interphalangeal joint, necessitating reduction, and 12 fingers had serious soft tissue injury to the terminal phalanx, including nail(bed) injury. Forty-four fractures were operated on and received osteosynthesis (44/214, 21%).

Thirty-two fingers were primarily amputated and could not be replanted, or needed secondary amputation (32/214, or 15%).
Ten out of 44 osteosyntheses (23%) were considered inadequate by the panel. Treatment plans at the A&E Unit and Outpatient Clinic combined were not correct in 48/406 cases (12%; 22 patients were only seen at the A&E Unit). Most fractures healed uneventfully (146/182, or 80%; 32 primary or secondary amputations were excluded: mostly distal phalangeal crush injuries). Thirty-six fractures did not heal properly: 25 fractures ended in malunion, eight fractures ended probably in malunion (follow-up period was to short), two fractures ended in nonunion, and one fracture ended probably in nonunion. Mean follow-up was 296 days (median 294; SD 61; range 188-404).
On average, people with a phalangeal or metacarpal fracture had to visit the hospital for their fractures seven times (median 4; SD 12; range 1 to 98): on average one time at the A&E Unit (median 1; SD 0.3; range 1 to 2), three times at the outpatient clinic (median 3; SD 2.9; range 0 to 22), and three times at rehabilitation/hand therapy (median 0; SD 11; range 0 to 88).
Hospital admission (when operated on) lasted on average 3.6 days (median 2.0; SD 4.3; range 0 to 17), for on average 1.5 fracture operations per patient (median 1.0; SD 0.8; range 1 to 4). Costs for hospital treatment of phalangeal or metacarpal fractures ranged from €193 for a single A&E Unit visit, to €23,205 (mean €1987; median €768, SD €2976). The highest costs were for a patient with four operations, 16 days at the hospital and a total of 80 visits to the hospital (78 outpatient clinic and two A&E Unit visits).
'Days off work' were collected by contacting all patients.
One-hundred-fifteen patients (71%) could be contacted. One of these patients refused to cooperate.
The non-contacted patients (46, or 29%) did not respond to five consecutive phone calls on differing hours (morning, afternoon or evening) in an eight week period, or the documented phone numbers proved incorrect and could not be retrieved otherwise. Injury was not substantially different in the group of patients that could not be contacted (i.e., number of fractures per patient and percentage of associated injury was within 5% of contacted group).
People with paid employment lost on average 32 days of work (median 15; SD 53; range 0 to 206) due to the injury.
For *costs of treatment*, the following variables had a statistically significant correlation: circumstances of trauma, operation, number of fingers involved, and number of amputations.
For *number of outpatient clinic visits*, the following variables had a statistically significant correlation: dominant hand injury, type of employment, circumstances of trauma, associated injury, number of fingers involved, number of amputated digits, operation, and follow-up time.
For *days in the hospital* (when operated on), the following variables had a statistically significant correlation: energy of trauma, circumstances of trauma, number of fingers involved, and number of amputations.

For *number of operations*, none of the variables had a statistic correlation. For *days off work* (when employed), the following variables had a statistically significant correlation: type of work, operation, and number of fingers involved.
Statistical details are shown in tables 3-6.

Table 3: *Statistical details of factors influencing number of outpatient clinic visits. Poisson regression and natural logarithms of data were used in analysis. Values presented here are calculated back to normal values.*

Variable	Value	Estimate direct multiplication factor	95% confidence interval		P-value
			Lower bound	Upper bound	
Dominant hand injury	**No**	1.67	1.26	2.22	< 0.001
	Yes	1	1	1	
Circumstances of trauma	**Home-street**	0.40	0.26	0.62	< 0.001
	Work	0.41	0.24	0.70	
	Traffic	1	1	1	
Associated injury	**Extensor**	0.96	0.51	1.78	= 0.01
	Amputation	1.76	1.02	3.03	
	Terminal phalanx soft tissue injury	0.68	0.27	1.73	
	Luxation	1.99	1.23	3.23	
	None	1	1	1	
Number of fingers involved		1.50	1.28	1.75	< 0.001
Operation		2.56	1.76	3.74	< 0.001
Number of amputations		0.70	0.57	0.86	= 0.001
Type of employment	**Employed**	0.69	0.49	1.03	< 0.05
	No job	0.60	0.40	0.89	
	Self-employed	1	1	1	
Follow-up time (in days)		1.00	1.00	1.01	< 0.005

Table 4: Statistical details of factors influencing days in the hospital. Uni-Anova multiple linear regression and natural logarithms of data were used in analysis. Values presented here are calculated back to normal values.

Variable	Value	Estimate direct multiplication factor	95% confidence interval		P-value
			Lower bound	Upper bound	
Energy of trauma	Low energy	0.42	0.24	0.72	< 0.005
	High energy	1	1	1	
Circumstances of trauma	Home-street	0.26	0.10	0.66	< 0.05
	Work	0.28	0.10	0.79	
	Traffic	1	1	1	
Number of amputations		0.76	0.59	0.99	< 0.05
Number of fingers involved		1.55	1.20	2.01	= 0.001

Table 5: Statistical details of factors influencing days off work. Poisson regression and natural logarithms of data were used in analysis. Values presented here are calculated back to normal values.

Variable	Value	Estimate direct multiplication factor	95% confidence interval		P-value
			Lower bound	Upper bound	
Type of work	Blue collar	3.74	1.47	9.55	= 0.005
	White collar	1	1	1	
Operation		2.34	1.10	4.98	< 0.05
Number of fingers involved		1.62	1.17	2.23	< 0.005

Table 6: *Statistical details of factors influencing costs of treatment. Uni-Anova multiple linear regression and natural logarithms of data were used in analysis. Values presented here are calculated back to normal values.*

Variable	Value	Estimate direct multiplication factor	95% confidence interval		P-value
			Lower bound	Upper bound	
Circumstances of trauma	Home-street	0.59	0.36	0.96	< 0.05
	Work	0.48	0.27	0.84	
	Traffic	1	1	1	
Operation		4.50	3.25	6.23	< 0.001
Number of fingers involved		1.60	1.26	2.01	< 0.001
Number of amputations		0.71	0.55	0.92	< 0.01

Discussion

In any course of treatment, it is important to know what is at stake and what is to be expected of the stakeholders. In the first place, raising awareness of the impact of a 'minor' injury as a phalangeal or metacarpal fracture, was worth the effort of this study. For instance, it was surprising to learn that outpatient clinic visits ranged from one up to a maximum of 98 visits in a year's period (98 visits: this patient suffered a severe post-traumatic complex regional pain syndrome).

The hospital costs, days in the hospital, number of operations, number of outpatient clinic visits, and period off work in the course of treatment of phalangeal and metacarpal fractures were objectified in a teaching hospital. Hospital costs differ in different countries and in different times.
An earlier study on economics in hand injuries in 1990 of 'O Sullivan showed an average cost of IR£474 for a hand injury. In that study, all incoming hand injuries of the A&E Unit were included, and lacerations of the hand constituted the largest group of patients. Only patients with a job were included, and missed labour costs were taken into account[3]. In our study, only hand injuries with a phalangeal or metacarpal fracture were included. Although missed labour costs were not taken into account in our calculations, mean costs were higher: € 2109. The different inclusion criteria, a different health care system, and inflation explain the difference in costs with the study of 'O Sullivan.
As additional data, for instance data on wages of patients, were not collected, it was not possible to make any estimation on socio-economic costs of lost production, let alone the fact that in the field of health economics many different methods prevail for calculation of such indirect costs with highly variable results[3,6].

Number of hospital days, number of operations, and number of outpatient clinic visits provide us with information on the impact of hand fracture treatment for the patients. Undoubtedly, for instance a high number of visits has a great impact on patients' lifes and daily routines.
In the perspective of efficiency of care, the numbers of operations and outpatient clinic visits are of interest. In twelve patients, two operations were performed, in four patients three operations were performed, while one patient was operated on four times. Most of the secondary operations concerned the removal of osteosynthesis material or tenolysis.
As the outpatient clinic visits are concerned, there is some improvement potential. For fracture treatment, an uneventful course in a conservatively treated fracture, would result in about three outpatient clinic visits: the first visit one week following the trauma, to check the alignment; the second visit six weeks following the trauma, to check on bony healing, and the last visit four to six weeks later, to check on mobility. In an operated fracture, with removal of osteosynthesis material, two or three visits might be added. In this study, 11 patients had more than six (range: 7-22) outpatient clinic visits with the fracture treating physicians. Of these patients, eight suffered a high-energy injury, with concomitant soft tissue injury in nine patients, and on average there were 2.5 fractures per patient. Clearly, open fractures with multiple digit injury may have a higher potential for a complicated course of treatment, but one might wonder if outpatient clinic visits adding up to 22, or hand therapy sessions adding up to 88, still contribute to improved healing.

Days off work following a hand injury with phalangeal and/or metacarpal fractures, ranges from on average six days to 102 days in published studies[4,7,3,8]. The mean number of days off work in our study was rather high. A few patients with severely injured hands accounted for most of days off work. More than 50% of working people returned to work within 10 days, and more than 75% within 30 days. Also, in the Netherlands, patients are standard compensated financially for sick leave, which is known to have a strong negative effect on return to work[9].

A number of variables had a statistically significant influence on the outcome measures. Familiarity with the significant variables can help us in predicting duration of treatment regimens and early planning/allocation of resources for the treatment of hand injuries. The significant variables were: dominant hand injury, circumstances of trauma, energy of trauma, associated injury, number of fingers involved, number of amputations, operation, type of employment, type of work, and follow-up time.
Some of these variables will be discussed.

Circumstances of trauma seems to be a predictor of number of outpatient clinic visits, days in the hospital, and costs. This effect is caused by the skewed data of the 'traffic' group. In this small group of 12 patients out of 161, one patient suffered a complicated course of illness, an extended and prolonged treatment regimen (with 98 outpatient clinic visits!), and excessive costs as compared to the other patients. This patient suffered a metacarpal fracture, four metacarpo-phalangeal luxations, and developed a severe, refractory post-traumatic complex regional pain syndrome.

The ‘number of amputations’ negatively influenced the number of outpatient clinic visits. There are several reasons for this. In the first place, an amputated finger obviously needs less rehabilitation efforts as compared to a fractured finger with osteosynthesis and concomitant significant soft tissue injury. Secondly, usually amputated fingers do not need frequent follow-up and X-rays, as fractured fingers do.
The ‘number of amputations’ also diminished the number of days in the hospital and the costs of treatment. Sometimes, amputations are performed at the A&E unit, instead of in the operating theatre, which is always combined with at least one day of hospital care. These procedures were counted as ‘operations’, but without the forthcoming costs and days in the hospital.

In accordance with literature, this study showed that blue collar workers had significantly longer time off work as compared to white collar workers[10].

Several studies underscore the importance of a proper diagnosis and treatment (plan) at the A&E Unit[7,11,12]. It was unexpected to find that an inadequate treatment plan, an inadequate osteosynthesis, a malunion, or a nonunion did not have a statistically significant correlation with the outcome end points that we chose.
A possible explanation could be a too short follow-up period to prove any relationship. In general, following a fracture treatment, at first the functional result will be awaited before planning any additional treatment, e.g. correction osteotomy. Since there is no fixed time-frame for a secondary treatment, we chose to investigate only the ‘short-term’ outcome.
Also, since the assessment of treatment plans, quality of osteosynthesis, and osseous healing by the senior authors was done at the end of the study period, no extra treatment was initiated following this assessment. Therefore no consequences in number of operations, number of outpatient clinic visits or hospital costs can be expected. The supervision at the outpatient clinic by staff members did not lead to a significant increase in any of the end points of this study, following initial wrong inadequate treatment or inadequate osteosynthesis.
One might also argue that the assessment that was performed lacks the nuances of everyday practice. The assessment was done by studying X-rays and following the strict definitions and guidelines of a protocol.
A treatment plan or result of osseous healing might seem inadequate in a retrospective assessment, but be the best result attainable given the clinical situation and personal circumstances of a patient.

In a previous study no strong correlation between impairment and disability was found, emphasizing the fact that impairment and disability are distinct entities[13] (impairment defined as lack of functional or structural integrity; disability defined as restriction in execution of tasks. WHO, 2001: 'International Classification of Functioning, Disability, and Health'). Likewise in this study, inadequate treatment, inadequate osteosynthesis, or malunion had no correlation with for instance days off work. Probably personal adaptation following impairment, or the professional skills that are required for a job, outweigh the importance of a malunion of a phalangeal fracture.

In conclusion, we quantified hospital costs, number of hospital visits, number of operations, number of days in the hospital, and period off work following hand injury with a phalangeal or metacarpal fracture. As measured in these endpoints, consequences of a phalangeal or metacarpal fracture can be severe. A number of variables that influence these end points were identified. These variables can be helpful in early allocation of resources in treatment of hand injuries.

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Discussion

As stated in the introduction, hand fractures occur frequently and usually heal uneventful. However, hand fractures can be complicated by deformity from no treatment, stiffness from over treatment, and both deformity and stiffness from poor treatment (Swanson, 1970).
Our ongoing effort to improve results of our (operative) treatment of fractures of the phalanges and metacarpals led to this thesis.

The aim of this study was to answer the following questions:

- What is the state of the art in operative phalangeal fracture treatment (*Chapter 2*)?
- What are our own results of bone healing in operative phalangeal fracture treatment, as compared to published series? What are the risk factors for impaired bone healing (*Chapter 3*)?
- What is the objective functional outcome following operative phalangeal fracture treatment in our own series? What are the risk factors for diminished functional outcome? Can we predict functional outcome (*Chapter 4*)?
- What is the relationship between objective functional outcome and subjective functional outcome data (*Chapter 5*)?
- Does phalangeal and metacarpal fracture treatment according to protocol lead to good results in our hospital? Why (not) (*Chapter 6*)?
- Is the impact of phalangeal and metacarpal fracture treatment substantial enough - in an economic and logistic perspective - to warrant improvement of (organisation of) care (*Chapter 7*)?

State of the art in operative phalangeal fracture treatment

In *chapter 2* we present the results of a comprehensive Medline literature search in which all current modalities and indications for surgical treatment of extra-articular phalangeal fractures were studied. The incidence of phalangeal fractures can be as high as 3% of all patients visiting the Emergency Unit of a University hospital[1]. Fractures are mostly work-related and crush is a frequent mode of injury[2]. In this chapter the indications for operation were assessed, and the preferred current operative treatment modalities of phalangeal fractures are described, with pros and cons for each modality. We composed an evidence-based guideline for operative treatment of phalangeal fractures, ranked according to location and geometry of the fracture. Although most aspects of operative treatment of extra-articular phalangeal fractures are covered in this chapter, it should not be considered as a comprehensive manual. Every patient, every fracture, every fracture mechanism, and every concomitant soft tissue injury poses its' own challenges to (judicious use of) osteosynthesis, skill of the treating surgeon and postoperative treatment regimen.

An important observation was done in the study of DaCruz et al. In his study the protracted healing processes of injuries with fractures of the distal phalanges were described, with 70% of patients still suffering serious complaints six months following injury[3]. The common opinion that these are minor injuries requiring minor treatment deprives patients of the proper treatment of these serious injuries. Education of physicians usually treating these injuries is warranted and easy consultation of a hand surgeon should be available.

Bone healing

Subsequently, we retrospectively analysed the results of operative treatment of phalangeal fractures at our department of Plastic, Reconstructive, and Hand Surgery of the Erasmus University Medical Center (Erasmus MC), Rotterdam, the Netherlands, and compared those results to literature (*chapter 3*). Also, risk factors for malunion and nonunion were identified.
All 350 patients with 666 phalangeal fractures that were operatively treated in the period between 1980 and 1997, were included.
The number of severe injuries in this series was high, with multiple digit injuries and frequent associated significant soft tissue injury involvement. The complication rates of infection, malunion, and nonunion were comparable to most published series, describing less extensive injuries.
This could imply a better result in our series, although a high fracture rate per se is not reported to be a risk factor for complications following treatment of phalangeal fractures, so no conclusion can be drawn from that statement. Furthermore, if we compare our series to the series of Ip[2], our nonunion rate was higher: 6% versus 3% respectively (other reported nonunion rates in literature are derived from studies with completely different inclusion criteria or rigidly prescribed osteosynthesis modalities[4-7]). However, the study of Ip had on average less extensive injuries, and much less significant soft tissue injury, which is a risk factor for nonunion[2,8].

As mentioned above, we observed the injuries of our series to be severe, with on average 1.9 fractures per patient and mostly comminuted fractures with significant soft tissue injury. All available other studies on operative treatment of phalangeal fractures had lower fracture rates, ranging from 1 to 1.63 fractures per patient[2,4-7,9-26].
Our high fracture rate was partly explained by the selection that was made - the study focusing solely on admitted patients with operative treatment -, partly by the heavy industry cases referred to our clinic, and partly because replantation cases were also included in our study. A fourth explanation was not mentioned or elaborated upon: indications for surgery. The retrospective nature of the study precludes a specified statement on indications for operative treatment. It can be hypothesized that our threshold for surgery was too strict, denying operative treatment for less extensive, single-digit injuries. When these less extensive, single-digit injuries would have been included, i.e. would have been operated upon, our series would be better comparable to the published series of Ip and Chow[2,22,27,28]. Including less complicated injuries in our series might improve our reported results of osseous healing.

Unfortunately, retrospectively it is not possible to gain insight in the indications for surgery, nor is it possible to get a comprehensive overview of all fractures that were referred to our hospital. All (hand) fractures that are presented at the Accident and Emergency (A&E) Unit, are screened by Emergency doctors (who resort under the Traumatology department), Traumatology residents, or Orthopaedic surgery residents. Possibly, a number of the above mentioned 'less extensive, single-digit injuries' which might need operative treatment, were in fact (under-)treated conservatively in our hospital. Furthermore, over-treatment of fractures in other reported series is also possible.

In conclusion, our series informed us on the validity of our current practice of osteosynthesis. Our study provided recommendations for future improvement of operative treatment. In case of a bony defect, it is advisable to add cancellous bone graft primarily, when good soft tissue coverage is present. Also, when using external fixators, extra attention should be paid to proper reduction and/or timely adjustment of the fixator postoperatively.

Objective and subjective functional outcome

After this analysis of results of bone healing, we reported functional outcome following operative treatment of phalangeal fractures in *chapters 4 & 5*. For this purpose, we studied a selection of the group of patients above. Our study population contained patients with severe injuries with multiple, operatively treated phalangeal fractures, and with a combination of risk factors. In a ten year period, 112 patients matched the inclusion criteria, of which 78 (70%) were eligible for testing in our study. This relatively large group of patients made it possible to statistically prove that risk factors 'level of fracture' (which phalanx), 'arthrodesis', and 'associated tendon injury' were determinative or preponderant in limiting finger motion following severe injury. For the possible combinations of these risk factors, the resulting functional deficit could be assessed. The results of this study enable a valid statement when predicting quantification of loss of digital motion in an injured digit, although the standard deviation was rather high in some instances (up to 61^0).

When reviewing literature on functional outcome, we were triggered by the lack of relevant quantitative data, which would be applicable for our purposes. There was substantial information on the individual risk factors for diminished function. Diminished function was sometimes expressed as percentage unsatisfactory or poor results, and was sometimes expressed as average total active motion (TAM)[2,6,7,15,16,20,22,27,29-31]. However, in our department of Plastic, Reconstructive, and Hand Surgery, at the Erasmus MC, we usually encounter a combination of risk factors, for which there are no published results to compare with. The second observation that we made while studying literature, was the lack of uniform nomenclature or definition of excellent/good/fair/poor results.

Almost every study used its own classification, for no apparent reason.
In order to clarify the issues stated above, we performed a study that was described in *chapter 4* of this thesis.

As was elaborated on in chapter 4, almost every author used his own definition of appreciation of digital function. In order to make use of the common denominator of different studies in which the TAM of 180^0 was the dividing line between 'poor' function on one side and fair/good/excellent function on the other side, we chose to use this TAM (180^0) as a simple division between 'unsatisfactory' and 'good', for reasons of simplicity and uniformity.

Most authors use objective outcome measures as 'total active motion' of a digit as a mere synonym of 'digital function'. However, digital function is not only a result of total active motion, but also a result of strength, speed of movement, sensibility, the requirements of desired tasks, and perception of the patient.
The World Health Organisation (WHO) issued conceptual frameworks on 'function' and related topics. According to the WHO, function depends on the interplay of (lack of) structural integrity and desired tasks or actions in which contextual factors as environmental and personal factors have a role as well. Besides these factors, psychological stress related to the trauma is important and needs to be addressed[32,33]. Hence, when only using objective tests when evaluating (treatment of) patients with hand injuries, important aspects of patients' (perception of) functioning could be underestimated. Therefore, a strong correlation between objective and subjective digital function tests would be desirable. In *chapter 5* we studied the relationship between the results of the clinically most widely used objective and subjective tests: the American Medical Association (AMA) impairment rate and the subjective Disabilities of the Arm, Shoulder and Hand (DASH) score, respectively.

The nuances and differences between impairment and disability are best explained by using the definitions of the WHO.
In 2001, the 'International Classification of Functioning, Disability, and Health' provided the following definitions:

Impairment: lack of functional or structural integrity.
Disability: restriction in activities or participation, restriction in execution of tasks.

The medical processes of impairment rating and disability determination for compensable injuries remain a source of confusion and debate among physicians[34]. Physicians are focused on impairment and improvement of functional integrity, for instance increasing total active motion or strength. Patients are focused on performing tasks and activities or restrictions herein. As mentioned above, a direct link or strong correlation between these different points of view would be desirable in the clinical setting.

There are several studies that have tested for correlations between different objective hand function tests and more functional outcome tests. These are summarized in the following table:

	Valpar Small Tools Test	Jebsen Hand Function Test	Functional Live Activity Test	Period off work	Severity of injury	Patient Evaluation Measure	Sollerman Hand Function Test
AMA	- [34]	- [34]	- [34]				
HISS*				+ [35-39]			
HFS**				+ [36]	+ [36]	+ [36]	
Subjective estimation of hand function							+ [40]

"-" means no statistically significant correlation; "+" means significant correlation

*) HISS: Hand Injury Scoring System

**) HFS: Hand Function Score

However, no study compared the clinically most used AMA and DASH tests. In our study, we found no substantial correlation between the AMA impairment rating and the DASH score in this patient group. This should help us, as treating physicians, realize that objective outcome measures as TAM or grip strength are only part of the functional demands and perceptions of a patient.

Quality of treatment

In *chapter 6* the results of a prospective audit of current hand fracture management in the Erasmus MC are presented.

At the start of this study, an evidence-based fracture treatment guideline was handed out to every hand fracture treating physician in the hospital. Prospectively, diagnoses and results of treatment were assessed. In the study period of seven months (Sept 2005 - Apr 2006), 230 fractures in phalanges or metacarpals could be included in the study. Diagnosis was correct in 83% of cases. Treatment plan was correct in 89% of cases. Fracture treatment led to good bony healing in 80% of cases, and 81% of osteosyntheses was correct. Incorrect diagnosis was scored mostly for incorrect classification; incorrect treatment plan was scored most frequently for insufficient reduction and conservative treatment instead of osteosynthesis.

Although our percentage scores in the end points of this study proved to be comparable to published series, still a considerable number of individual patients suffered form misdiagnosis, mistreatment, and malunion. Therefore, every possible effort should be undertaken to improve our performance.

Measures as regular audits, structural training of theory and procedures, and standard feedback and supervision, can lead to a substantial improvement of quality of care[41-43]. Examples of successful improvements of care following measures as above mentioned are:

- The Advanced Trauma Life Support routine. This routine enhanced the knowledge and established institutionalised protocolised treatment of (life threatening) trauma.
- The efforts of the Institute for Healthcare Improvement: implementation of six simple measures, concerning every day intensive care unit practice, prevents substantial numbers of deaths.
- The success of the American Society of Anaesthesiologists: after a series of structural improvements in the early eighties of the last century, the number of anaesthesia-related deaths was reduced by a twenty fold.

Also logistic changes can improve care. In an A&E Unit study on hand injuries, Davis suggested the centralization of knowledge within one specialty[44]. This would concentrate knowledge and experience, which would benefit the quality of care. An inspiring example of this mechanism is the success of the Shouldice clinic in Ontario, Canada: perfection of the repair of inguinal hernia by highly experienced physicians who are trained to do nothing but hernia repair.
Prerequisites and keys to success in the examples listed above, are structural and lasting changes in the (organisation of) care practice, and a shared awareness of all involved specialties of the significance of the problem. Increasing the awareness of all involved physicians and stakeholders can be done by auditing and publishing, like in this sixth chapter, but also by demonstrating what consequences originate from (inadequate) fracture treatment. Since no lives are at stake, as in some of the above examples, economic consequences and quantification of the efforts of treating physicians and patients following (inadequate) treatment might help the care providers envision the need to improve treatment of hand fractures.

Logistics and economics

In *chapter 7* of this thesis, results of a prospective study on human and hospital efforts and direct costs in treating phalangeal and metacarpal fractures are presented.
On average, hospital costs were €1987 (range €193 to €23,205), patients had to visit the outpatient clinic seven times (range 1 to 98), hospital admission (when operated on) for treatment of phalangeal or metacarpal fractures lasted 3.6 days (range 0 to 17) for on average 1.5 operations (1 to 4), and people

with paid employment lost 32 days of work (range 0 to 206) due to injury. Ten out of 18 variables were identified to have a statistical relation with the endpoints. These were: dominant hand injury, circumstances of trauma, energy of trauma, associated injury, number of fingers involved, number of amputations, operation, type of employment, type of work, and follow-up time.

We made the observation that an inadequate treatment did not result in higher costs, more operations, more days in the hospital, more frequent outpatient clinic visits, or more days off work in the early post-traumatic period. This lack of correlation was unexpected and could not quantify the necessity for improvement of the quality of hand fracture treatment, as was one of the objectives of this study.
In the discussion of chapter 7, we hypothesized the short follow-up time, the retrospective assessment of quality of treatment in this prospective study, and individual patient factors to be responsible for this lack of correlation. An additional explanation could be that the patient usually is not medically educated and accepts the result of his/her treatment, learns to live with it, and does not pursue further action. Our study in chapter 5 already showed that personal adaptation can overcome serious functional deficits following hand trauma. Also, not every malunion in the metacarpal or phalanx leads to serious functional problems, depending on the location, the type of malunion, the severity of the deformity, the time elapsed since injury, joint involvement and the presence or absence of tendon or joint adhesions[45,46].

The extra efforts of the patients and inconveniences in daily life following inadequate treatment are difficult to quantify. A study with longer follow-up, more strict supervision and intervention when indicated in the early post-traumatic period might establish the relationship between the adequacy of treatment and the outcome parameters of chapter seven. However, the optimal management of undesirable sequelae is prevention[8]. Therefore in the mean time, our medical professionalism, in which we strive for optimal results, should be the main drive for improvement of care.

Concerning costs of treatment, this study was performed in a transitional period (from Sep 1, 2005 to Apr 1, 2006) in which the old payment structure in the medical setting in the Netherlands was being replaced by a new one. In the old structure, every procedure, hospital stay, or outpatient clinic visit was separately charged. In the new payment structure, every combination of diagnosis and treatment (in Dutch called 'diagnose-behandel-combinatie', or 'DBC') has its own unique price, based on average costs of such a combination (analogous to the Diagnosis Related Groups or 'DRG's' and derivatives, as originally used for Medicare patients in the USA).
This transitional period provided substantial administrative confusion. Therefore, every hospital bill in this study had to be checked manually, and if necessary corrected and replaced by costs actually made.

In retrospect, this transitional period was not the optimal time frame to perform this cost-analysis study.
In conclusion, impact of phalangeal and metacarpal fracture treatment is substantial in an economic and logistic perspective. However, inadequate treatment did not add to this impact.

Future perspectives
The study of chapter 7 showed a great impact of phalangeal and/or metacarpal fracture treatment in an economic and logistic perspective for the fracture treating professionals and the personal lives and daily routines of the patients. We assessed an opportunity for improvement on the quality of treatment. Published and unpublished observations in the line of these studies lead to the following recommendations on the improvement of care:

- Obligate thorough and regular training in hand traumatology theory for all hand fracture treating physicians. This includes:
  - indications for operative therapy
  - knowledge of fracture geometry and classification
  - knowledge of trauma mechanisms and fracture dynamics
  - knowledge of hand anatomy and hand dynamics
  - training in application of plaster casts and knowledge of plaster techniques
  - training in hand osteosynthesis techniques and theory
- Regular exposure to hand surgery
- Strict protocolisation of A&E Unit hand fracture treatment
- Adequate supervision in training situations
- Standard fluoroscopy during operation
- Standard control antero-posterior and transverse x-rays following reduction, splint application, or osteosynthesis. Preferably these x-rays should be authorised by a hand surgeon.

Most practical would be centralisation of hand surgery within one team of specialists, who are trained to do hand surgery, have daily exposure to hand surgery, and are skilled in hand fracture treatment. In doing so, experience of this team will increase, skills are trained regularly and chances of good outcome for the patient will be maximised.

In conclusion
An evidence-based comprehensive phalangeal fracture treatment protocol was composed. We retrospectively assessed acceptable ‘osseous’ and functional results of operative treatment of phalangeal fractures at the department of Plastic, Reconstructive, and Hand Surgery of the Erasmus MC, comparable to published series of less extensive injuries. Risk factors for poor results were identified.

We found the AMA and DASH score to have a low correlation, which led us to realize that the 'functioning' concept should prevail in our clinical mindset. A prospective audit of metacarpal and phalangeal fractures showed acceptable results for the integral treatment at the A&E Unit by the fracture-treating specialists combined, it also revealed improvement needs. Finally, the efforts of patients, treating physicians and therapists, and the hospital organisation in the treatment of these injuries, were quantified. It was shown that treatment and sequelae can be intense for patient, physician, and therapists, and costs can be substantial.

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Summary

Fractures of the phalanges and metacarpals of the hand occur frequently. Inadequate treatment can lead to nonunion, malunion, and infection. Also, function of the involved finger or hand can be diminished, leading to impairment and disability.
In order to assess and possibly improve our practice of hand fracture treatment, studies were performed that led to this thesis.

Following a comprehensive Medline search, an evidence-based protocol and manual of operative treatment of extra-articular fractures of phalanges was compiled (*chapter 2*). This chapter starts with an introduction on incidence, etiology, and classification, and describes the different treatment modalities of operative phalangeal fracture treatment. Furthermore, according to localisation, a preferred treatment is suggested.

The results of operative treatment of phalangeal fractures at the department of Plastic, Reconstructive, and Hand Surgery of the Erasmus University Medical Center (Erasmus MC), Rotterdam, the Netherlands were retrospectively assessed (*chapter 3*). Records and radiographs of 350 patients with 666 operatively treated phalangeal fractures in a 17 years time frame were studied (1980-1997). Complication rates of bone healing proved to be comparable to other published series, describing less extensive injuries. The nonunion rate was six percent, the malunion rate was nine percent, and the infection rate was two percent. Infections, segmental bone loss and associated (neuro-)vascular injury were risk factors for nonunion. Replantation and the use of external fixation devices predisposed for malunion.

Subsequently, the digital functional loss in severely injured hands was quantified (*chapter 4*). Patients who had multiple phalangeal fractures necessitating operation in a 10-year time period (1987- 1997) were tested, using measurements of total active movement. Seventy-eight patients with 228 phalangeal fractures were available for follow-up. In 88 fingers, the fractures ended in amputation and were excluded from the study. In the resulting 140 fractures, 74 (53%) had a good result (movement >180^0 for fingers 2-5, and > 98^0 for the thumb), and 66 (47%) had an unsatisfactory result. Associated soft tissue injury, level of injury, and arthrodesis were risk factors for diminished function. A quantification of digital functional loss for combinations of these risk factors was made, offering prognostic information for clinical use. Intra-articular fractures and multiple fractures within the same finger predisposed for arthrodesis. Despite the extensive and severe injuries, more than half of patients had good results, which is comparable to other published reports, describing hand injuries with less extensive trauma.

Although objectifiable functional loss - or impairment - is an important outcome tool for the treating physician, impact of a finger injury on the patient and his daily activities - or disability - is at least of equal importance.

In the next study (chapter 5), correlation between impairment and disability was assessed following treatment for severe hand injuries with multiple phalangeal fractures, adjusted for comorbidity and duration of follow-up.

Impairment evaluation was performed using the guidelines of the American Medical Association (AMA) impairment evaluation for the upper extremity. Disability evaluation was done using the Disability of the Arm, Shoulder and Hand (DASH) questionnaire.
Seventy-eight patients with 228 operatively treated phalangeal fractures were available for testing, with a mean follow-up of 7.5 years. No statistically significant correlation existed between AMA impairment ratings for the hand and DASH module scores. There were weak correlations between AMA impairment ratings for the arm and total body and DASH module 'function' scores. The lack of a strong correlation emphasizes the clear distinction between impairment and disability, and underscores the need for more individualized, ADL-oriented treatment regimens.

In a prospective study, an audit was performed on quality of treatment of phalangeal and metacarpal fractures.
In a 7 months period (Sept. 2005 - Apr. 2006), all incoming fractures at the Accident and Emergency Unit (A&E Unit) of the Erasmus MC were included (*chapter 6*). Residents of Traumatology, Orthopaedic Surgery, and Plastic Surgery, treating these fractures at the A&E Unit and the Outpatient Clinic or Operating room, were asked to classify the fractures and to record the treatment plan. Also, results of treatment were scored.
In the aforementioned period, 182 patients were seen at the A&E Unit with 230 phalangeal or metacarpal fractures. Eighty-three percent of diagnoses were correct and 89% of treatment plans were according to protocol, comparable to other published series. Thirty-two fractured fingers were primarily or secondarily amputated and 159 of 198 fractures (80%) healed properly. Osteosynthesis was deemed adequate by an independent expert panel in 42/52 (81%) of cases.

In the final study of this thesis (*chapter 7*), the financial and logistic impact of treatment phalangeal and metacarpal fractures was assessed in a prospective study. Of patients that were studied in the audit of chapter 6, hospital costs, hospital visits, days in the hospital, number of operations, and period off work were recorded. Eighteen variables that possibly influenced outcome data were statistically tested. These were: age, sex, follow-up time, type of work, type of employment, dominant hand trauma, energy of trauma, circumstances of trauma, pre-existing impairment, associated injury, operation, number of fingers involved, average number of fractures/finger, number of amputated digits/patient, articular involvement, number of inadequate osteosynthesis/patient, number of malunions/patient, number of incorrect treatment plans/patient.

One hundred and sixty-one patients with 214 phalangeal or metacarpal fractures were included in this study. On average, hospital costs were €1987 (range €193 to €23,205), patients had to visit the outpatient clinic seven times (range 1 to 98), hospital admission (when operated on) for treatment of phalangeal or metacarpal fractures lasted 3.6 days (range 0 to 17) for on average 1.5 operations (1 to 4), and people with paid employment lost 32 days of work (range 0 to 206) due to the injury.
For *costs of treatment*, the following variables had a statistically significant correlation: circumstances of trauma, operation, number of fingers involved, and number of amputations.
For *number of outpatient clinic visits*, the following variables had a statistically significant correlation: dominant hand injury, type of employment, circumstances of trauma, associated injury, number of fingers involved, number of amputated digits, operation, and follow-up time.
For *number of operations*, none of the variables had a statistic correlation.
For *days in the hospital* (when operated on), the following variables had a statistically significant correlation: energy of trauma, circumstances of trauma, number of fingers involved, and number of amputations.
For *days off work* (when employed), the following variables had a statistically significant correlation: type of work, operation, and number of fingers involved.

In the final chapter (*chapter 8*) the following recommendations for improvement of treatment of phalangeal and metacarpal fractures are provided:
- Regular training in hand traumatology theory for all hand fracture treating physicians
- Regular training in hand osteosynthesis techniques and theory for all hand fracture treating physicians
- Regular exposure to hand surgery and, more specific, exposure to hand fractures (operative) treatment modalities
- A&E Unit hand fracture treatment according to protocol
- Adequate supervision in training situations
- Standard fluoroscopy during operation
- Standard control antero-posterior and transverse x-rays following reduction, splint application, or osteosynthesis. Preferably these x-rays should be authorised by a hand surgeon.

Samenvatting

Fracturen van phalangen en metacarpalia van de vingers komen vaak voor. Verkeerde behandeling kan leiden tot nonunion, malunion en infectie. Ook kan de functie van de vinger of hand verminderd zijn na een fractuur, leidend tot functieverlies en beperking in dagelijkse handelingen. Teneinde de kwaliteit van (be-)handelen van handfracturen in het Erasmus Universiteit Medisch Centrum (Erasmus MC), Rotterdam, te evalueren en mogelijk te verbeteren, werd een aantal studies uitgevoerd, die tot dit proefschrift hebben geleid.

Na een uitgebreide literatuurstudie werd een behandelprotocol opgesteld voor de operatieve behandeling van extra-articulaire phalanx fracturen (*hoofdstuk 2*). In dit hoofdstuk worden eerst de incidentie, etiologie en de indeling van fracturen besproken, vervolgens de verschillende behandelprincipes en -methoden van operatieve behandeling van phalanxfracturen. Tot slot wordt afhankelijk van locatie en type fractuur, een behandeling van voorkeur voorgesteld.

De resultaten van operatieve behandeling van phalanxfracturen op de afdeling Plastische, Reconstructieve en Handchirurgie van het Erasmus MC werden retrospectief vastgesteld (*hoofdstuk 3*). Patiëntendossiers en röntgenfoto’s van 350 patiënten met 666 operatief behandelde phalanx fracturen werden bestudeerd (periode 1980-1997). De complicatie percentages van fractuurgenezing bleken in overeenstemming met percentages in de literatuur, waarin overigens minder uitgebreide letsels werden beschreven. Het nonunion percentage was zes procent, het malunion percentage negen procent en het infectie percentage twee procent. Infecties, substantieel botverlies en bijkomende letsels van de neurovasculaire bundel van de vingers bleken risico factoren voor het ontstaan van nonunion. Replantatie procedures en het gebruik van externe fixateurs resulteerden frequenter in het ontstaan van malunion.

Vervolgens werd in een studie het functieverlies van vingers na ernstige handletsels vastgesteld (*hoofdstuk 4*). Bij patiënten met multipele, operatief behandelde phalanxfracturen (periode 1987-1997) werd de functie van aangedane vingers getest op bewegingsbeperking (‘totale actieve bewegingsuitslag’). Voor deze studie bleken 78 patiënten met 228 fracturen beschikbaar voor onderzoek. Bij 88 vingers had het letsel geleid tot amputatie en kon niet getest worden. Bij de resterende 140 fracturen was er bij 74 vingers (53%) sprake van een goed resultaat (bewegingsuitslag >180^0 voor vingers 2-5, > 98^0 voor de duim), bij 66 (47%) een onbevredigend resultaat. Bijkomend weke delen letsel, niveau van het letsel en aanwezigheid van een arthrodese waren risicofactoren voor een verminderde functie. Deze verminderde functie kon worden gekwantificeerd voor de verschillende combinaties van risicofactoren, hetgeen belangrijke prognostische informatie verschaft. Intra-articulaire fracturen en multipele fracturen in één vinger bleken significant vaker tot arthrodese te leiden. Ondanks de ernst van de letsels die in deze studie werden getest, bleek toch meer dan de helft van de patiënten een goed resultaat te hebben, vergelijkbaar met percentages in de literatuur, waarin minder ernstige letsels werden onderzocht.

Hoewel objectiveerbaar functieverlies, hier verlies van bewegingsuitslag, een belangrijke uitkomstmaat is voor de behandelend arts, is de impact van een vingerletsel voor de patiënt, ofwel de subjectieve beperking in zijn dagelijkse handelingen (ADL), minstens even belangrijk.
In de volgende studie (*hoofdstuk 5*), werd de correlatie getoetst tussen deze twee uitkomstmaten. Voor deze metingen werd dezelfde patiëntengroep getest als beschreven in hoofdstuk 4.

Bij het vaststellen van functieverlies werd gebruik gemaakt van de richtlijnen van de American Medical Association (AMA) voor de bovenste extremiteit. Voor het vaststellen van beperking in ADL werd de zg. Disability of the Arm, Shoulder, and Hand (DASH) vragenlijst gebruikt.
De gemiddelde duur tussen trauma en de hierboven genoemde tests was minimaal 2 jaar, gemiddeld 7,5 jaar. Er werd geen statistisch significante relatie tussen de AMA score voor de ‘hand’ en de DASH modules gevonden. Tussen de AMA scores voor de ‘arm’ en ‘hele lichaam’ aan de ene kant en de DASH module ‘functie’ bleek een zwakke relatie aanwezig. Het ontbreken van een sterke relatie benadrukt het duidelijke verschil tussen objectiveerbaar functieverlies en de subjectieve beperkingen die een patiënt ervaart. Dit betekent ook dat in het behandeltraject van een patiënt met een handletsel, het behandelend team zich ook moet richten op deze subjectieve beperkingen.

Het volgende hoofdstuk (*hoofdstuk 6*) beschrijft een prospectieve studie naar de kwaliteit van behandeling van phalanx en metacarpale fracturen op de Spoed Eisende Hulp (SEH) van het Erasmus MC. Gedurende 7 maanden (sept. 2005- april 2006) werden al deze fracturen geincludeerd. Aan de behandelende artsen van Traumatologie, Orthopedie en Plastische Chirurgie werd gevraagd de fractuur te classificeren en het behandelplan te omschrijven. Na eerste opvang op de SEH werd de behandelend artsen op een volgend behandelmoment, op de polikliniek of op de operatiekamer, nogmaals gevraagd naar de correcte diagnose en het behandelplan. Tenslotte werd het resultaat van de behandeling geëvalueerd.
In deze periode werden 182 patiënten met 230 phalanx of metacarpale fracturen in de studie geincludeerd. Bij 83% van de fracturen werd de diagnose correct genoteerd, het behandelplan was in 89% volgens protocol. Deze percentages komen overeen met soortgelijke onderzoeken in de literatuur.

Tweeëndertig vingers werden geamputeerd door aard en uitgebreidheid van het letsel. Tachtig procent (159/198) van de fracturen genas in een goede stand. Osteosynthese werd adequaat bevonden in 81% (42/52) van de gevallen.
De laatste studie (prospectief) van dit proefschrift (*hoofdstuk 7*), behandelt de financiële en logistieke gevolgen van phalanx en metacarpale fracturen. Van patiënten in hoofdstuk 6 werden de ziekenhuiskosten, het aantal ziekenhuisbezoeken, het aantal operaties, het aantal dagen in het ziekenhuis en de arbeidsongeschiktheidsperiode vastgesteld. De mogelijke correlatie tussen deze uitkomstmaten en achttien variabelen werd statistisch getoetst. Dit waren: leeftijd, geslacht, duur follow-up, type werk, arbeidsbetrekking, letsel dominante hand, aard van het letsel, omstandigheden van het letsel, pre-existente beperkingen, bijkomend weke delen letsel, operatie, aantal vingers met letsel, aantal amputaties/patiënt, aantal fracturen, gewrichtsschade, inadequate osteosynthese, aantal malunions/patiënt en aantal verkeerde behandelplannen/patiënt.
Na exclusie van patiënten met (ernstig) bijkomend letsel konden gegevens van 161 patiënten met 214 phalanx of metacarpale fracturen worden geanalyseerd. Gemiddeld waren ziekenhuiskosten €1987 (van €193 tot €23.205), bezochten patiënten het ziekenhuis zeven keer (1-98 keer), duurde ziekenhuisopname 3,6 dagen (0-17 dagen), voor gemiddeld 1,5 operaties (1-4 operaties) en waren patiënten met een betaalde betrekking gemiddeld 32 dagen arbeidsongeschikt (0-206 dagen) door het trauma.

De volgende variabelen bleken van invloed op de *ziekenhuiskosten*: omstandigheden van het letsel, operatie, aantal vingers met letsel, aantal amputaties.
De volgende variabelen bleken van invloed op het *aantal ziekenhuis-bezoeken*: letsel dominante hand, arbeidsbetrekking, omstandigheden van het letsel, geassocieerd weke delen letsel, aantal vingers met letsel, aantal amputaties, operatie, duur follow-up.
Geen van de variabelen bleek statistisch verband te houden met het *aantal operaties*.
De volgende variabelen bleken van invloed op het *aantal dagen* in het ziekenhuis (indien geopereerd werd): aard van het letsel, omstandigheden van het letsel, aantal vingers met letsel, aantal amputaties.
De volgende variabelen bleken van invloed op de *arbeidsongeschiktheids-periode* (bij betaald werk): type werk, operatie, aantal vingers met letsel.

In het laatste hoofdstuk (*hoofdstuk 8*), worden de volgende aanbevelingen gedaan voor het verbeteren van behandeling van phalanx en metacarpale fracturen:

- Regelmatige training in theorie van traumatologie van de hand voor alle artsen die betrokken zijn bij behandeling van handfracturen
- Regelmatige training in osteosynthese technieken en theorie voor alle artsen die betrokken zijn bij behandeling van handfracturen.

- Regelmatige bedrijven van handchirurgie en ervaring met operatieve behandeling van hand fracturen.
- Behandeling van fracturen volgens protocol.
- Adequate supervisie in opleidingsomstandigheden.
- Standaard controle AP en dwarse röntgenfoto’s na repositie, aanbrengen van gips en/of osteosynthese. Bij voorkeur beoordelen van deze foto’s door een handchirurg.
- Standaard gebruik van röntgen doorlichting tijdens operatie.

Dankwoord

Veel dank aan allen die geholpen hebben: dank aan de promotor, de leden van de promotiecommissie, opleiders, begeleiders, mede-auteurs en mede-onderzoekers, collegae, (poli-) kliniek assistentes, secretaresse's, röntgenarchiefmedewerkers, (SEH) verpleegkundigen en allen die nog niet genoemd zijn, maar wel een bijdrage geleverd hebben. Onderzoek is teamwork!!

Curriculum Vitae

Frederik van Oosterom werd op 18 september 1968 geboren in Nieuwerkerk aan den IJssel. Na het behalen van het VWO diploma (c.l.), Murmellius Gymnasium Alkmaar in 1986, begon hij aan de studie geneeskunde op de Universiteit van Amsterdam, welke na enige sportieve onderbrekingen werd afgerond in 1992. In 1995 werd het artsdiploma gehaald.
Als arts-onderzoeker experimentele chirurgie in het Academisch Medisch Centrum, Amsterdam, werd zijn interesse gewekt voor de microchirurgie en plastische chirurgie. Na enkele arts-assistentschappen werd hij in het Erasmus Medisch Centrum, Rotterdam in 1998 aangenomen voor de opleiding Plastische Chirurgie, onder leiding van prof.dr. S.E.R. Hovius.
De tijd tot de start van de opleiding werd gevuld met onderzoek dat uiteindelijk leidde tot dit proefschrift, en met werkzaamheden als strategisch management consultant bij McKinsey & Company in Amsterdam.
Van oktober 2000 t/m september 2003 werd de vooropleiding algemene chirurgie doorlopen in het St. Antonius Ziekenhuis te Nieuwegein, onder leiding van dr. P.N.M.Y.H. Go. Hierna volgde de opleiding plastische chirurgie in het Erasmus Medisch Centrum in Rotterdam onder leiding van prof.dr. S.E.R. Hovius, welke werd afgerond in oktober 2006.
In deze tijd vonden de laatste klinische studies plaats van dit proefschrift en werd het fellowship-examen van de European Board of Plastic, Reconstructive and Aesthetic Surgery met goed gevolg afgelegd.
Momenteel is hij werkzaam als plastisch chirurg in het Medisch Centrum Alkmaar.