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Functional treatment of Colles fracture

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In 1814, the Irish surgeon Abraham Colles published an article about a very common fracture of the distal radius that now bears his name. Since this publication, numerous articles have been written concerning this particular fracture. The great number of articles and the great variety of recommended therapies, indicates that until now, no consensus exists on the best treatment of Colles fractures. The high percentage of unsatisfactory end results and the high incidence makes the Colles fracture a medical problem.

The history of fracture treatment reveals a continuous search for improvement of the therapy. In the past, fracture treatment consisted of reduction and immobilisation of the injured extremity with splints or casts, untill osseous union had occurred. Immobilisation was felt to be necessary for bone healing. As a result of this, muscle and bone atrophy, long periods of disability and joint stiffness were often seen.
Some decades ago operative intervention with anatomical reduction and stabile osteosynthesis gained considerable popularity. By early excercises quick functional recovery could be obtained. Important drawbacks to operative intervention were the risks of infection and pseudarthrosis. In recent years, functional fracture treatment was developed. The basis of this functional treatment is to permit and encourage early motion and function in the injured extremity by means of an external brace. Such a brace merely stabilises the fracture, necessary for reduction of pain and maintenance of alignment, however it does not immobilise the fracture. Sarmiento (163), propagated this method as an alternative to osteosynthesis where early restoration of function is imperative for an optimal functional result without the drawbacks of surgical intervention. He believes that "motion and excercise is good for tissue healing, rehabilitation and prevention of disability of joints and limbs and that the sacrifice of absolute anatomic reduction of fractures by his method is a small price to pay for the restoration of function and rapid healing".

The treatment of the Colles fracture underwent the same evolution. Various different forms of plaster cast immobilisation and many different types of operative intervention have been used. Recently, closed functional treatment was also advocated in the treatment of Colles fractures. In 1975, Sarmiento (159) developed a functional brace for Colles fractures which permits early volar flexion and ulnar deviation but prevents dorsal flexion and radial deviation of the wrist and prevents pronation of the forearm. The forearm is kept in fixed supination by extension of the brace above the elbow. Flexion in the elbow is permitted, the last 45 degrees of extension in the elbow is restricted. In this way, early motion and function of the wrist during the healing period is achieved and is encouraged. In retrospective studies, Sarmiento claimed with his method a good anatomical and functional end result and an early functional recovery (159, 162).

In the University Hospital Maastricht, The Netherlands, it was noticed that a considerable number of patients kept loss of function and pain after a Colles fracture. The usual treatment consisted of reduction and immobilisation in a conventional dorsal lower arm plaster of Paris splint for four weeks followed by excercises. Functional treatment of Colles fractures seemed to be a promising method in order to achieve better results.

1.2 Aim of the thesis

The aim of this thesis is to investigate in a prospective clinical study whether functional treatment of Colles fractures indeed leads to better results than conventional plaster treatment in order to establish the application field of functional treatment for this kind of fracture.

In the following two chapters, a review of literature is given with the purpose of searching for methods to evaluate possible differences between methods of treatment, to standardize the management of the injury, and to reveal the state of art of the management of the Colles fracture necessary for the design of the study.

CHAPTER 2

THE NORMAL WRIST AND HAND

2.1 Introduction

In this chapter a review of literature is restricted to those aspects of the normal wrist and hand that apply to a study on the therapy of Colles fractures. No general description of anatomy of the wrist region as found in standard anatomy textbooks is given as it is not the aim of this thesis to contribute to this subject.

2.2 Motion in the wrist region

The wrist can angulate in any direction and by a combination can circumduct. It has a most complex articular configuration which does not lend itself readily to simple mechanical description and interpretation (54). The wrist joint functions with 3 parallel longitudinal chains. In each of these chains the proximal carpal functions as an intercalated bone (97). The specific shape of these intercalated bones establishes a simultaneous movement in the radio-carpal and the mid-carpal joints which makes dorsal flexion, volar flexion, ulnar deviation, radial deviation or combinations possible. The centre of rotation in the dorsal-volar flexion and ulnar-radial deviation plane is located in the head of the capitate bone (6,127,189,201). The reported mean values of maximal excursion of motion in the wrist are as follows (3,28,86,134,189):

dorsal flexion	50^{o}-80^{o}	ulnar deviation	30^{o}-46^{o}
volar flexion	60^{o}-85^{o}	radial deviation	15^{o}-29^{o}

The American Academy of Orthopaedic Surgeons (3) advises recording wrist motion with a goniometer with the forearm in pronation. The measurements should be based on the principal of the neutral zero method (The neutral position is the zero starting position).

In the forearm pronation and supination takes place, involving the proximal and distal radio-ulnar joints. The mean values of the maximal excursion of pronation and supination are (3,86):

pronation	80^{o}-90^{o}	supination	80^{o}-90^{o}

According to the American Academy of Orthopaedic Surgeons (3) pronation and supination should be measured with the elbow at right-angle flexion, thus blocking rotary motions of the humerus.

2.3 Function of the hand

Impaired wrist function due to a Colles fracture may alter hand function as the wrist is the key joint for proper function of the hand (128,184). Several fundamental motor functions of the hand can be distinguished (25,96):

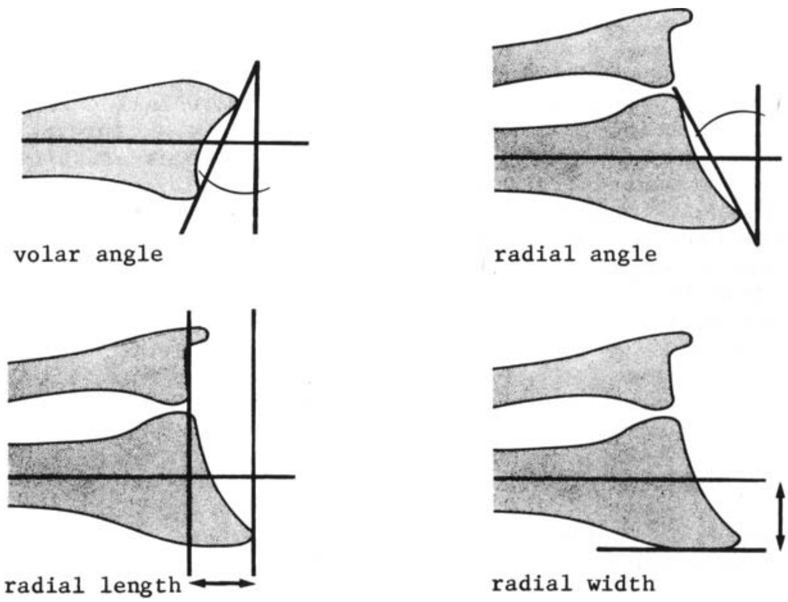
- Opening of the hand consisting of finger extension and of abduction of the thumb.
- Closing of the hand, consisting of finger flexion and adduction and consisting of flexion, adduction and opposition of the thumb.

- Grip; several types can be distinguished (89):
  power grip as when grasping a cylinder
  ball grip as when grasping a ball
  pinch grip as when picking up tiny objects
  three point grip as when holding a pen
  key grip as when opening a door with a key.

2.4 Radiographic anatomy

Three types of radiographic measurements are commonly used in anatomical evaluation of the distal radius. The measurements are recorded against the longitudinal axis of the radius. In A.P. and lateral vieuws the longitudinal axis is defined as a line through two points located in the middle of the diaphysis of the radius at distances of 3 cm and 6 cm proximal to the radio-carpal joint (71) (Figure 2.1).

Figure. 2.1 Radiographic measurements



The volar angle measured on lateral vieuws is defined as the angle between a line joining the volar and dorsal margins of the distal radial surface and a line perpendicular to the longitudinal axis of the radius (73,109). The volar angle averages 11^{o}-12^{o}, ranging from 0^{o}-21^{o}, with a standard deviation of 4.3 (71,74).

The radial angle measured on A.P. vieuws is the angle between a line joining the tip of the radial styloid and ulnar corner of the distal radial surface and a line perpendicular to the longitudinal axis of the radius. The average radial angle is 23^{o} with a range of 13^{o}-30^{o} and a standard deviation of 2.2 (71,74,86,164).

The radial length measured on A.P. vieuws is the distance between two perpendiculars to the longitudinal axis of the radius, one drawn through the tip of the radial styloid process and the other tangential to the distal articular surface of the ulna. The radial length avarages 12 mm with a range of 8-18 mm and a standard deviation of 2.3 (71,86,164).

A fourth type of measurement seems to have practical implications for the Colles fracture (Paragraph 3.6). The radial width measured on A.P. vieuws is the distance between the longitudinal axis and the most lateral point of the radial styloid (Figure 2.1).

2.5 Conclusion

Parameters for external evaluation of motion in the wrist region and motor function of the hand, and for anatomical evaluation of the distal radius, as far as necessary for this study, are well described in literature.

CHAPTER 3

THE COLLES FRACTURE, REVIEUW OF LITERATURE

3.1 Historical Review

The first description of the Colles fracture was probably given by Claude Pouteau in 1783 (145). He was the first to differentiate the fracture of the lower distal radius from wrist dislocations. In 1814, in the Edinburgh Medical and Surgical Journal the Irish surgeon Abraham Colles (38) published an article "On the fracture of the carpal extremity of the radius." In this paper he described the dorsally displaced radius fracture, occurring in the distal one and a half inch, that now bears his name. His method of treatment consisted of traction to reduce the displaced fracture and application of volar and dorsal tin splints. With great self-assurance, he remarked "The cases treated on this plan have all recovered without the smallest defect on deformity of the limb, in the ordinary time for the cure of fractures". In poorly treated fractures, he stated "One consolation only remains, that the limb will at some remote period again enjoy perfect freedom in all its motion and be completely exempt from pain: the deformity, however, will remain undiminished through life".

3.2 Definition

The Colles fracture is regarded as a complete transverse fracture of the distal 3 cm of the radius in adults with dorsal angulation, dorsal displacement, radial angulation and radial displacement, often with a supination displacement and frequently with impaction of the distal fragment (9,34,55,86,131,142,144,192). Some authors also regard a non-displaced transverse fracture of the distal radius to be a Colles fracture (8,163).

3.3 Pathogenesis

The Colles fracture occurs most often after a fall on the outstretched hand with the wrist in dorsal flexion (9,23,73). The distal end of the radius forms the entire bony articulation between the forearm and the hand and is thus subject to the major forces in a fall on the outstretched hand (41). The majority of the energy however, is absorbed by the soft tissues and joints of the hand (137). The transition zone between the dense cortex of the shaft and the cancellous distal part surrounded by only a thin layer of cortical bone is a point of least resistance and therefore often the site of the fracture (41,42,183). The amount of energy to produce a Colles fracture decreases with age (2).

Cadaver experiments showed that fractures of the distal radius are produced when the dorsal flexion of the wrist varies from 40 to 90 degrees (73,111). The type of fracture depends on the position of the wrist and the direction and magnitude of the violence (9,23,73). In Colles fractures, the usually sharp, not comminuted fracture on the volar side contrasts with the comminuted fragments on the dorsal and radial side. This suggests that the volar surface of the radius may first fracture by distraction with the fracture propagating and compacting cancellous bone on the dorsal and radial side which then becomes comminuted (54). This comminution of the cortex invites dorsal and radial angulation of the distal fragments (34,55). The periosteum on the volar side ruptures. The periosteum and the fibrous part of the tendon sheaths on the dorsal surface as well as the ligaments on the wrist remain essentially intact (41,42,50).

Both the distal radio-ulnar joint as well as the radio-carpal joint may be involved in the fracture (73). Subluxation of the radio-ulnar joint will occur only with lesions of the triangular fibrocartilage, attached to the ulnar styloid and the medio-dorsal part of the distal radius. There can be a rupture of the fibrocartilage or an avulsion of one of its insertions (74). Weigl and Spira (195) demonstrated by arthrography that the triangular fibrocartilage shows either perforation or detachment in about 60 percent of the Colles fractures. However, autopsy showed perforation in 41 percent of normal wrists. Avulsion of the ulnar styloid process accompanies Colles fractures in 50 to 60 percent of the cases (9,31,55,71,109,183).

3.4 Incidence

The Colles fracture is one of the most frequent fractures in man; only fractures of fingers and ribs are more frequent (42,58). It accounts for 8-15% of all bone injuries (76,86,183). Alfram and Bauer (2) found an incidence of 0.17% a year in the population of a big city in Sweden. The mean age is between 48 and 50 years for women and 45 years for man (9,30). Before the age of forty, the incidence of Colles fractures is about equal in males and females. In men, the incidence rises but slightly from forty to eighty years of age, whereas in women the incidence rises 8-10 times from forty to sixty after which it remains constant (2,63,135). The overall male to female ratio is about 1 to 5 (73,109). This difference correlates with an increased incidence of osteoporosis after the menopause in woman (12,135,147).

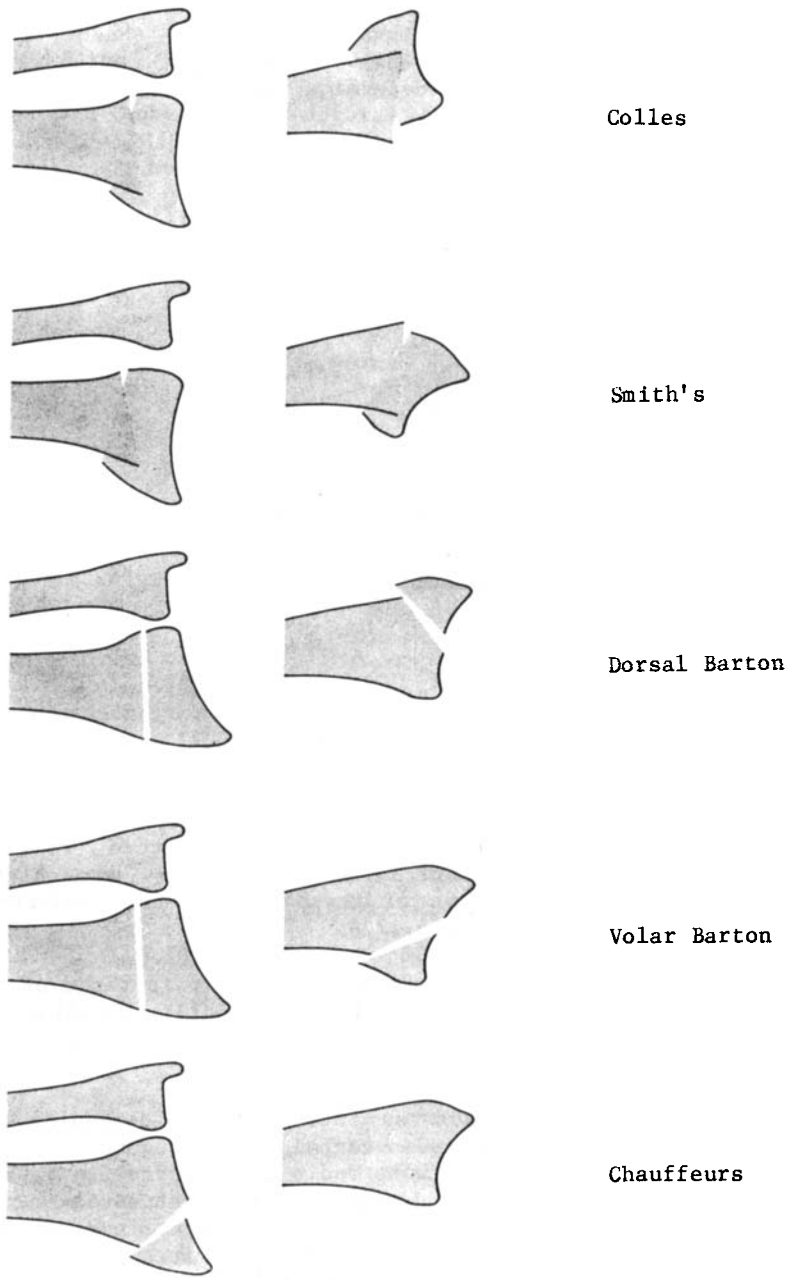
3.5 Clinical examination

The clinical appearance in a markedly displaced Colles fracture is that of the classical dinner fork and bayonet deformity; the carpus and hand are displaced in respectively a dorsal and radial direction. The ulnar side might show a volar prominence of the distal ulna (40,55). The hand is held in pronation and is somewhat flexed. Supination is impossible. Active movement of hand and fingers is either markedly or completely limited (42). A fracture with displacement usually produces a large extravasation of blood and great swelling which begins quickly and may involve the hand, fingers and entire forearm (41).

3.6 Radiographic examination

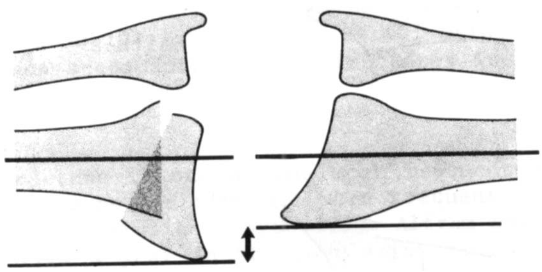
Radiographic studies in both anterior-posterior and lateral projection are required to confirm the diagnosis, to determine the type of fracture and to assess the degree of displacement (21,73,109). The Colles fracture must be distinguished from other fractures of the distal radius, like the Smith's fracture with volar displacement of the distal fragment, the dorsal Barton fracture (dorsal margin fracture), the volar Barton (volar margin fracture) and the chauffeurs fracture (isolated radial styloid fracture) as these require a different treatment (Figure 3.1) (11,13,32,55,67,86). The Colles fracture however, represents well

Figure 3.1 Different types of distal radius fractures



over 90 percent of all distal radial fractures (86). Accompanying fractures or dislocations, in the same extremity are rare (9,15,132). Subluxation of the distal radio-ulnar joint may be apparent on the lateral projection, particularly if the superimposed triquetral shadow no longer lies in line with the distal ulna (55). Volar angle, radial angle and radial length can be measured to determine the degree of displacement and impaction. Van der Linden and Ericson (112) added the so-called radial shift, defined as the difference in radial width between the injured and uninjured side (Figure 3.2). In their opinion the radial shift combined with the volar angle displacement (volar angle difference between the injured and uninjured wrist) provides enough information about the displacement as the two criteria are independent of each other.

Figure 3.2 Radial shift



3.7 Fracture classification

Many different classifications of the Colles fracture have been developed, depending on the direction of displacement (51), the presence of injury to the triangular fibrocartilage (126,187), the localisation of fracture lines (150), the degree of comminution (110,139), combinations of joint involvement and degree of displacement (74,76,109,163) or combinations of joint involvement and ulnar styloid fracture (73). In one classification system no less than 34 different types were distinguished (59). At present the systems of Frykman (73) and Sarmiento (163) have gained recognition (35,43,50,55,172).

Frykman's classification is most frequently used. It is based on the involvement of the radio-carpal joint, radio-ulnar joint and ulnar styloid and consists of a scale of 8 different types with an increasingly unfavourable prognosis (Figure 3.3) (73).

Sarmiento classified Colles fractures into 4 types, depending on displacement and involvement of the radio-carpal joint (Figure 3.4) (163).
Type 1 non-displaced fractures without radio-carpal joint involvement
Type 2 displaced fractures without radio-carpal joint involvement
Type 3 non-displaced fractures with radio-carpal joint involvement
Type 4 displaced fractures with radio-carpal joint involvement
According to Sarmiento (163) this classification is based on anatomic, therapeutic and prognostic considerations. Type 1 and 3 are regarded as stable fractures. Type 2, if properly reduced, might be stable, however, redisplacement might occur. Type 4 is supposed to be the most difficult and unstable fracture.

Figure 3.3 Frykman's fracture classification

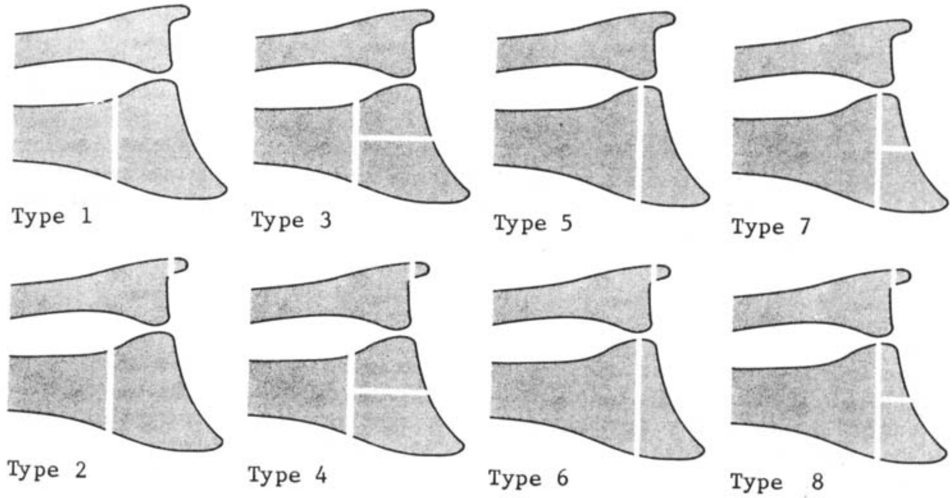
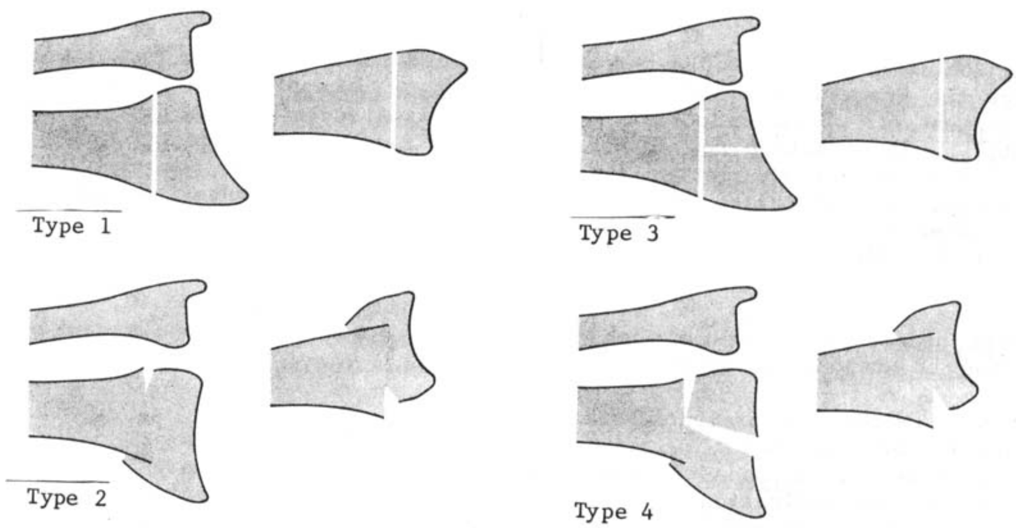


Figure 3.4 Sarmiento's fracture classification



3.8 Management of the injury

The Colles fracture should be regarded as an injury of the wrist region accompanied by a Colles type fracture of the distal radius. The injury is not only limited to the bone. The damage to the soft tissues should also be taken into consideration (177). Not only the treatment of the fracture in a restricted sense (technique of immobilisation or stabilisation) but also anaesthesia, method of reduction, post-reduction care, rehabilitation and prevention or treatment of complications are part of the management of the injury (109,177).

3.8.1 Anaesthesia

Several forms of anaesthesia for the reduction in displaced fractures exist. Local infiltration of 10-20 ml of lidocaine, 1 or 2% into the fracture haematoma is commonly used (21,62,73,109,110). Additional infiltration of the ulnar side might be usefull (17,130). Dinley and Michelinalus (53) found local anaesthesia very effective and without adverse effects or infection in 280 patients. General anaesthesia has the advantage of muscle relaxation (36,76,83) but its use is limited because patients cannot be treated on an out patient-basis (73). Bultitude et al (25) in a prospective study prefered i.v. diazepam alone to general anaesthesia. Regional intravenous anaesthesia (Biers anaesthesia) and axillary plexus block anaesthesia have also been described as safe procedures (36,84,85,146).

3.8.2 Reduction

Reduction in displaced fractures should be done as soon as possible (109, 144) although Frykman (73) found no significant difference between immediate and 24 hours delayed reduction. Satisfactory reduction can almost always be secured by closed methods (46). Two methods are commonly used:

1. According to Charnley (34) impaction should be freed by hyperextension, immediately followed by volar flexion and pronation to "lock" the fragments (110). The usually intact periosteum and fibrous parts of the tendon sheath on the dorsal surface forms a soft tissue "hinge" which must be kept under tension to maintain the reduction (46). However, hyperextension might add unnecessary additional injury to the soft tissues (29,30).
2. Böhler (20) described a method of traction for 2-5 minutes to disimpact the fragments. Additional manual pressure is applied on the distal fragments to obtain reduction. This method is frequently used (13,17,23, 36,71). The traction can either be applied manually (21) or by the use of gravity. For the latter finger trap traction is used for about 15 minutes with so called "Chinese finger traps", while countertraction is achieved by a sling over the humerus suspended on a weight of 3-10 kg with the elbow flexed to 90 degrees (13,24,36,50,56,159,182).

In the literature, no indication was found for the amount of displacement necessary to reduce the fracture or how much displacement can be accepted without the necessity for reduction.

3.8.3 Methods of fracture treatment

3.8.3.1 Introduction

Many different methods of immobilisation or stabilisation have been described. The indication for these different methods is the most controversial detail in the management of Colles fractures (109). This suggests that no method is completely satisfactory. The method chosen by the authors refect their opinion on the relation between the anatomical and functional end result. To those who assume a close causal relationship, the aim of the treatment is to produce an anatomical reduction and maintain this position till consolidation (5,9,10,17,26,30,31,35,36,37, 42,43,67,76,79,86,92,108,109,120,126,131,169,182,196). Others pointed out that even a significant collapse of the fracture fragments does not preclude a good functional end result (30,56,139,159,175). To some a good functional end result depends mainly on early exercises and fast consolidation (34,163). According to Charnley (34) a controlled collapse of the cancellous bone is the treatment of choice as this leads to quick periosteal union which is the best way to functional recovery. Hudson and Rusnack (88) and Spira and Weigl (175) believed that comminuted fractures of the distal radius can heal only by shortening of the radius. They performed no reduction at all, but treated comminuted fractures with primary resection of the distal ulna.

The different methods of treatment can be categorised in:
A. conservative treatment by: - immobilisation with plaster casts
- stabilisation with functional braces
B. operative treatment by : - skeletal fixation.
Operative treatment is mainly indicated for unstable fractures; stable fractures usually are treated conservatively. Comminuted fractures usually are regarded as unstable (36,43,50,56,83,92,163). Cooney et al (43) diagnosed instability in the presence of much comminution, severe dorsal angulation (20 degrees or more) or extensive intra-articular involvement. Redislocation is proof of instability to others (69,86). Minimally displaced or non-displaced fractures are treated conservatively as these are generaly considered to be stabile (42,72,86,148,163).

3.8.3.2 Immobilisation with plaster casts
Numerous techniques of plaster cast or splint immobilisation have been developed. The plaster should never extend beyond the metacarpophalangeal joints and should permit full finger motion (8,17,19,21,62,68,72,74, 76,86,110,120,150,170,192). Most frequently a below-the-elbow plaster cast or splint is used (17,19,21,34,68,71,73,109,110,120,150,170,173).

- Position of the wrist:
A position of the wrist between volar and dorsal flexion, combined with moderate ulnar deviation according to Böhler (12) is often used (73,109, 124,182). A position in moderate volar flexion and moderate to full ulnar deviation according to Charnley (34) is also common (17,67,68,72,74, 76,110,120,150,170,192). The Cotton-Loder position of forced full palmar flexion, ulnar deviation and pronation (45) is abolished nowadays because of its association with median nerve compression (75,86,117). Soren (173) placed the wrist in neutral position and made indentations on the radial and dorsal side of the plaster to prevent displacement. Stewart et al (180) concluded that the position of splintage does not influence the anatomical end result to a noteworthy degree.

- Position of the forearm:
A below-the-elbow plaster results in a neutral position of the forearm as pronation and supination are not fully restricted (17,21). Some authors proposed a supination position of the forearm with the help of an above-the-elbow plaster (12,55,62,113). Sarmiento et al (158) advocated this position as EMG studies showed reduced muscle activity of the brachioradialis muscle in supinated forearms. They claimed that this muscle, being attached to distal end of the radius, plays an important role as a deforming force, causing redislocation in Colles fractures. Others prefered an above-the-elbow plaster with the forearm in pronation (42,60,76,127). Wahlström (190) concluded in a prospective randomised study that contraction of the pronator quadratus muscle, attached to the distal radius, could cause redislocation resembling the original deformity. This muscle contracts mainly when the forearm is in supination, which makes the pronation position more suitable. Both Hinding (87) and

Pool (144) found in prospective studies that an above-the-elbow plaster cast has no advantages over a below-the-elbow plaster.

- Change of plaster:
Often the plaster is left unchanged for the whole immobilisation period. It can be adjusted by a new bandage after oedema has subsided (55) or might be completed to a circular plaster after some days (19,120). Sometimes the plaster is changed for a complete new one (72,74,170). A complete circular plaster from the beginning is seldomly used (124,173).

- Casting material:
Mainly plaster of Paris is used. New casting material like Isoprene (Orthoplast) or polyurethane may have the advantage over plaster of Paris of being lighter and water repellent. However, no difference in results was found with the use of different materials (151,160).

3.8.3.3 Functional treatment
Sarmiento et al (159,162,163) developed the conservative method of functional bracing of Colles fractures. By use of an external brace early motion and function is made possible, without operative fixation of fracture fragments. The brace stabilises the fracture, which is necessary for reduction of pain, maintenance of alignment and prevention of deformity, it does not immobilise the fracture fragments. This approach is based on the belief that immobilisation of the fragments and the joints above and below the fracture is not necessary for fracture healing (107). It is also based on the finding that the soft tissues of the injured extremity play a major role in providing the stability necessary for uninterrupted osteogenesis. Sarmiento and Latta (163) suggested that early motion at the fracture site enhances osteogenesis. To support this theory, they remarked on the rapid healing under constant motion of fractures of clavicles and ribs. They demonstrated in laboratory induced fractures that early function leads to early vascular invasion (107). The increased ingrowth of capillaries stimulated by muscle activity is accompanied by osteoblastic and osteoclastic activity. As early revascularisation comes from the surrounding tissues, osseous callus forms first in the periphery, forming an osseous cap over the fibrous callus and haematoma. Early function thus leads to early periosteal callus which is mechanically strong. This process is the quickest way to restore the strength of the fractured bone (107,129,161). Without movement of fracture fragments on the other hand periosteal callus is minimal (4). Here endosteal and end-to-end bridging callus predominates with less strength of the callus (129). Consequently, Sarmiento (163) stated that "rigid internal fixation of fracture fragments or complete immoblisation of the injured extremity violates the normal biological processes and changes the manner in which the fracture repairs itself. In this case fractures heal not because they are fixed or immobilised, but in spite of it. The early motion and function leads to a faster and better functional recovery, preventing stiffness and disability which is often encountered with immobilisation methods of treatment. Functional treatment approximates the natural reparative processes and the rehabilisation schemes which the body provides through pain as normal biological feedback mechanism." According to Sarmiento and Latta (163) undue attention has been paid to the importance of anatomical reduction of the fragments and maintenance of that position during healing, since the introduction of radiology in the assessment of fractures.

Sarmiento's functional bracing of Colles fractures consists of two phases. In the first week the fractured arm is immobilised in an above-the-elbow plaster splint with the elbow in flexion, the forearm in supination and the wrist in moderate ulnar and volar flexion. After that the splint is changed for an Isoprene brace that permits motion of the elbow till the last 45 degrees of extension and permits volar flexion of the wrist. It prevents pronation of the forearm and radial deviation and dorsal flexion of the wrist. The position of the forearm remains in supination. Although Sarmiento described that only early volar flexion with this brace is permitted, from the shape of the brace it can be concluded that early ulnar deviation is also possible. Sarmiento et al (162) found in a prospective study that displaced fractures functionally treated in supination showed less redislocation than displaced fractures functionally treated in pronation. No difference between pronation and supination position was seen in undisplaced fractures.

Recently Sarmiento's functional bracing of Colles fractures also has been used by others (16,26,33,178). Stewart et al (178) described in 1984 an even more functional bracing method with a below-the-elbow brace that only prevents dorsal flexion of the wrist. Pronation and supination are not fully restricted.

3.8.3.4 Skeletal fixation
The advocates of skeletal fixation all assume a close causal relationship between the anatomical end result and functional end result. Skeletal fixation is mainly used for unstable and comminuted fractures.

Various methods of operative fixation are recommended. Böhler (22) developed a method of self-contained traction, by incorporating Kirschner wires or pins in plaster. Many variations on this technique have been proposed by placing the wires or pins in different places (24,36,46,79, 83,79,83,121,164). De Palma (50) described a method of ulnar pinning, fixing the reduced distal radius to the ulna. In another method, wires were drilled through the radial styloid (10,13,39,40,108). Kapanji (94) used intra focal nailing to fix the fragments. Rush and Rush (154,159,) recommended internal fixation of the radius by an intramedullary pin. In the Roger Anderson technique (5) an external bar links percutaneous pins inserted into the second and third metacarpal bones and the distal radius (12,43,44). The Hoffman external fixation (18), the Hoffman mini-external fixation (98), the small A.O.-external device (91), the Wagner distraction-compression device (122) and other external fixation devices (43,167) have all been recommended in the treatment of comminuted Colles fractures. Forgon (69) applied a mini-external fixation, fixing the distal fragment to the metaphyseal part of the radius to prevent immobilisation of the wrist joint. Internal fixation of Colles fractures is seldomly used (105). To Marti and Polomski (122) absolute indications for open internal fixation and cancellous bone graft are the comminutive impression fractures in which the soft tissue hinge has no function in closed reduction. Intramedullary methylmethacrylate has also been described as a method of skeletal fixation (104).

No publications on prospective comparative clinical trials could be found concerning skeletal fixation methods in Colles fractures.

3.8.4 Management of a compartment syndrome

The management of a compartment syndrome is mentioned separately as its occurrence demands a departure from the usual management. Zimmerman (202) regarded Colles fractures in young patients to be high energy injuries with a subsequent risk of a compartment syndrome in the forearm. He advised volar fasciotomy and decompression of the carpal tunnel in this type of injury or in signs of ischaemia. After decompression and reduction skeletal fixation is applied. Only one case report was found on pressure recording in a compartment syndrome related to a Colles fracture (125).

3.8.5 The post-reduction period

The post-reduction period is the period between the application and the removal of the plaster, brace or fixation device. The patient should be instructed on the different side effects of the injury and management like swelling, numbness and discoloration of the fingers (68). The use of a sling to prevent swelling is recommended for 1 to 4 days (17,68,72, 150). Finger, elbow and shoulder exercise from the beginning, are of great importance (5,8,9,42,47,62,68,72,83).

In conservative treatment, the recommended immobilisation or stabilisation time is relatively short; 3 weeks (142), 4 weeks (17,62,72,76,124, 170), 5 weeks (21,58,73,109,150) or 6 weeks (13,74,80,111,120,163,173, 192) are mentioned. Wahlström et al (191) demonstrated by bone scanning that unstable fractures are healed and stable after 28 days and do not need longer immobilisation. For minimally and non-displaced fractures, 3 to 4 weeks immobilisation is advised (42,72,86,148).

Skeletal fixation requires a longer immobilisation period because of the slow union of the distracted fragments. The recommended immobilisation period ranges from 6-8 weeks (24,36,77,83,121) and 8-10 weeks (56,79, 164) up to 12 weeks (5).

3.8.6 The rehabilitation period

The rehabilitation period extends from the removal of the plaster, brace of fixation device until full recovery of function. Functional exercises should start immediately. Active functional exercises should be done by the patient himself, under proper medical supervision (73,86). Physical therapy is indicated for patients with poor motivation and when appropriate functional progress is absent (67,86). The average time off work after a Colles fracture is 2 to 3 months (31,164,172). A period of 4 months can be regarded as a reasonable time before full activity can be resumed (86). However, the final degree of recovery cannot be judged with certainty until a year after the injury (68,76). The grip strength of the hand seems a valuable parameter to assess the rehabilitation as it gives a good indication of the extremities' ability to function (141). In a review of 156 Colles fractures, Sarmiento et al (162) concluded that early function via functional bracing in supination leads to early recovery of range of motion and rehabilitation, although they never compared this with other methods of treatment. Both Bünger et al (26) in 1984 and Stewart et al (178) in 1984 did not found any difference in speed of recovery between functional bracing and below-the-elbow plaster immobilisation.

3.9 Complications

Complications in Colles fractures are important causes for unsatisfactory functional end results (73). Cooney et al (44) found 31% serious complications in 564 Colles fractures. The following main groups of complications can be distinguished:

1. Complications of applied techniques
2. Redislocation
3. Nerve injuries
4. Tendon injuries
5. Sudeck dystrophy
6. Malunion
7. Loss of radio-ulnarintegrity
8. Post-traumatic arthritis
9. Loss of motion and function
10. Persistent pain
11. Dupuytren contracture

3.9.1 Complications of applied techniques

Plaster casts or splints may cause pressure sores (44). If a plaster is too tight, oedema of the hand will develop. In long lasting oedema fibrine exudate induces fibrosis (80,82,103). Skeletal fixation may cause osteitis, pin tract infection, ulceration, pin breakage, neuropathy and stiff wrists. Green (79) experienced pin tract drainage in one third of his patients treated with pins in plaster technique. Marsh and Teal (121) found with the same technique in 8% paraesthesia and in 8% pin tract infection. With the use of the Roger Andersen external pin fixation Cooney et al (43) reported in 12% pin loosening.

3.9.2 Redislocation

No commonly accepted definition of redislocation was found. The indication for rereduction is not uniform; redislocation more than 10-15^{o} dorsal angulation, 4 mm radial length shift or 10^{o} or radial angle shift have been mentioned (17,37). Collert and Isacson (37) advised rereduction after 2 weeks because the fracture is then "sticky" and will not redislocate again. Cooney et al (44) reported a successfull rereduction in 92%. The recommended treatment after reduction varies from a new plaster to external fixation (44,92).

3.9.3 Nerve injuries

Nerve injuries associated with Colles fractures are usually reported in 0.2% to 5% of the cases (31,73,86,117,180). Mostly these concern the median nerve in its course through the carpal tunnel. Stewart et al (179) found a carpal tunnel syndrome in 17% three months after the fracture. Early median neuropathy is associated with reduction, direct nerve damage at the time of the injury, haematoma, swelling or the Cotton-Loder position of immobilisation (44,86,117,149). Gelberman et al (75) however, found no correlation between the amount of swelling and the carpal canal interstitial pressures. An acute carpal tunnel syndrome should undergo immediate operative decompression (44,75,192). Transient median nerve symptoms are common and usually caused by haemorrhage and swelling. Expectant treatment results in complete cure in most of the cases (119,176). Delayed median nerve injury that usually occurs after 6 weeks is caused by excessive callus formation, degenerative diseases, displaced bone fragments or malunion (44,86,101,133,149). Stewart et al (179) found no correlation between nerve compression and initial displacement; the final volar angle shift however seemed associated with the delayed carpal tunnel syndrome. Operative decompression is indicated if pain and loss of sensation are severe (31,43,176,180). Only a few authors (117,180) used electromyographic studies in stabilising the diagnosis and making an indication for surgery.

Ulnar nerve compression is rare (31,73,155,168,203). Paraesthesia of the radial nerve is uncommon and usually clears up spontaneously within a few weeks (41).

3.9.4 Tendon injuries

Spontaneous rupture of the extensor pollicis longus tendon is reported from 0.4 till 1% (31,44,48,73,165). It occurs usually 6 to 12 weeks after the trauma and is mostly seen after undisplaced or minimally displaced fractures (44,48,61,73,165). The rupture almost invariably occurs in the bony groove on the distal radius (48). The cause might be mechanical, through laceration of the tendon by bone fragments or callus or by a crush injury of the tendon during the hyperextension trauma (49,181, 188,192,198). In another theory a vascular aetiology is proposed; increased pressure in the non ruptured tendon sheeth due to hematoma or laceration of the mesotendon might disturbe the blood supply causing degeneration and rupture of the tendon (61,48,171). Tendon transfer of the extensor indicis proprius is the most commonly used procedure with excellent results (165,181,194).
Rupture of other tendons have been mentioned in connection with a Colles fracture but are extremely uncommon (44,118,138,156,174,199). Stenosing tendosynovitis is reported in 0.6-1.4% (30,103,174).

3.9.5 Sudeck dystrophy

Sudeck dystrophy is a term that encompasses a wide clinical spectrum and is closely related or identical with conditions like post–traumatic reflex dystrophy, post–traumatic sympathetic dystrophy, shoulder hand (finger) syndrome, osteoneurodystrophy and causalgic syndrome (7). The incidence in Colles fractures varies from 0.1% to 16% and should be suspected when pain, swelling and stiffness are out of proportion to the severity of the injury (9,44,72,73,86,106,109). It leads to a high degree of disability (73). Three different stages can be distinguished (Table 3.5) (7,90,106,186).

Table 3.5 Stages in Sudeck dystrophy

Stage 1:
- puffy oedema
- redness, hyperaemia
- pronounced pain out of proportion to the initial injury
- hyperesthesia
- hyperhidrosis
- redness over the metacarpophalangeal and proximal interphalangeal joints
- limitation of movement
- after 3-4 weeks beginning of spotty demineralisation or polar demineralisation in the epiphysical region as seen on radiographs

Stage 2:
- fussiform swelling
- tight shiny skin
- increasing diffuse pain
- hyperhidrosis, hyperaemia
- motion continues to decrease
- joints become fixed
- acute nodules due to palmar fascitis
- atrophy of the subcutaneous tissues
- scanty hair growth after 1 year
- brittle nails
- spotty demineralisation or polar demineralisation

Stage 3:
- hand : pale color, cool and dry
- skin : thin, tightly stretched with glossy appearance
- wide spread neuralgia
- stiff hand
- diffuse demineralisation of bone

The aetiology is not yet clearly understood. Among contributing factors, sympathetic over-activity, vasomotor reflexes, circulatory insufficiency, oedema, traumatic fracture reduction, rereposition, frequent changes of casts, malunion, psychological factors and endogenous factors have been mentioned (7,47,57,70,73,106,136,143). In the treatment sympathetic blocks, sympathectomy, guanethidine blocks, corticosteroids, vasodilatators, analgesics, immobilisation, active physiotherapy and hydroxyl radical scavengers have been advocated (42,57,70,78,106,136,192). Some authors believed that if activity is carried out from the beginning, this complication is very rare; they regarded active exercises to be the best prophylaxis (7,103,136,148).

3.9.6 Malunion
No commonly accepted criteria for malunion could be found. Malunion, mostly resulting from redislocation, might cause limitation of motion, cosmetic deformity and pain (44).Some authors adviseda corrective wedge osteotomy with interposing corticocancellous bone grafts, especially in young patients with an angulation deformity (44,65,166,193).

3.9.7 Loss of radio-ulnar integrity
Loss of radio-ulnar integrity is caused directly by extension of the fracture into the joint or indirectly by shortening of the radius (86, 100). Symptoms include restricted painfull pronation and supination sometimes with a disturbing click, weakness of grip, persistant pain on compressing the distal ulna and radio-ulnar joint, protruding distal ulna and laxity of the distal radio-ulnar joint (1,73,86,109,116). The latter can be assessed clinically by moving the ulnar head up and downwards in comparisson with the uninjured side (66,113). Frykman (73) found an incidence of 19% and regard it an important cause of unsatisfactory functional end results. For most authors, resection of the distal ulna (Darrag procedure) is the treatment of choice for complaints resulting from loss of radio-ulnar integrity (34,46,52,65,195). Good results, painless motion in the wrist region and improved cosmetic appearence have been reported after this procedure (1,44,46,65,116,140).

3.9.8 Post-traumatic arthritis
Post-traumatic arthritis is reported from less then 5% to over 40% (44, 73,74,109,113,170). This discrepancy arises from the use of different definitions (86). Some based the diagnosis on symptoms of painful motion and mechanical obstruction (44). Others on radiographic criteria like narrowing of the joint space, sclerosis, subchondral clearing and osteophyte formation (17,74,170). It is seen especially after intra-articular fractures. No reports on the onset were found. Selected cases have been treated by wrist fusion, proximal row carpectomy or total prosthetic arthroplasty (44,86).

3.9.9 Loss of motion and function
No generally accepted criteria for loss of motion and function were found. In Bacorn and Kurtzke's (9) retrospective study of 2132 cases, only 3% had no permanent loss of function. The most frequent permanent defect was reduced volar flexion in 95%. Frykman (73) found 10^{o} or more loss of motion in 77% of 431 Colles fractures. Loss of grip strength is recorded in 24 to 54% (9,31,73,164). Finger stiffness is found in 1 to 18% (73,74,159). Lloyd and Stangel (114) noted in 80% reduced strength of pronation and supination, being unrelated to the degree of malunion.

3.9.10 Persistent pain
Persistent pain is frequently associated with previously mentioned complications. It is described separately as this complaint might be the most annoying residual factor for the patient. Frykman (73) found persistent pain in 27% of his patients. Castain (31) reported moderate to severe pain in 39% in his series. Wringing out clothes, turning doorknobs, heavy lifting, pronation and supination under stress appear to be frequently painful for a year after the injury (30). During the same period changes of weather might be associated with pain (30,86).

3.9.11 Dupuytren contracture
Some authors mentioned the occurrence of a Dupuytren contracture in 0.2 to 3% of the cases (9,31,39,44). Stewart et al (179) found in 23 of their 209 patients palmar nodules and bands, six months after the injury.

3.10 Evaluation of the end results
To evaluate the subjective, functional, cosmetic and anatomical end results after Colles fractures, many different scoring systems have been used. Lidström (109) developed classifications to score the functional end result, anatomical end result and cosmetic end result (Table 3.6, 3.7, 3.8). These were used and modified by others (17,73,162). Gartland and Werley (74) developed a functional end result score system, based on the Mc Bride's (128) disability evaluation (Table 3.9). It has been used by various authors (36,50,56,69) and modified by others (26,31,43,115, 121,152,162,178). Many authors designed their own systems or classifications for the functional and anatomical end result (30,36,79,88,123,139, 142,164,169,170,175).

Table 3.6 Functional end result classification of Lidström (109)

1. Excellent:
   Function of the wrist unimpaired. No subjective symptoms. No deformity. Loss of dorsal flexion or palmar flexion not exceeding 15 degrees.
2. Good:
   Function of the wrist unimpaired. Negligible subjective symptoms. Deformity accepted if not producing subjective symptoms.
3. Fair:
   Function of the wrist less satisfactory for activities requiring special strength or extreme movements which must be avoided. Most pre-injury activities possible. Loss of motion, even if severe is accepted if not associated with subjective symptoms.
4. Poor:
   Working capacity diminished or general way of life affected. Cases with continuous pain.

Table 3.7 Anatomical end result classification of Lidström (109)

1. No or insignificant deformity: dorsal angulation not exceeding 0 degrees or shortening of less than 3 mm
2. Slight deformity: dorsal angulation of 1-10 degrees and/or shortening of 3-6 mm
3. Moderate deformity: dorsal angulation of 11-14 degrees and/or shortening of 7-11 mm
4. Severe deformity: dorsal angulation exceeding 15 degrees or shortening of at least 12mm
   The shortening is measured with the non-injured wrist as a standard

Table 3.8 Cosmetic end result classification of Lidström (109)

1. Normal appearance
2. Normal appearance except for prominence of the ulnar head
3. Slight radial deviation
4. Moderate to pronounced radial deviation, dinner fork deformity

Table 3.9 Functional end result score system of Gartland and Werley (74)

Residual deformity		
Prominent ulnar styloid		1
Residual dorsal tilt		2
Radial deviation of hand		2-3
	score range	0-3
Subjective evaluation		
Excellent: no pain, disability or limitation of motion		0
Good: occasional pain, slight limitation of motion, no disability		2
Fair: occasional pain, some limitation of motion, feeling of weakness in wrist, no particular disability if careful, activities slightly restricted		4
Poor: pain, limitation of motion, disability, activities more or less markedly restricted		6
	score range	0-6
Objective evaluation		
Loss of dorsal flexion	(<45°)	5
Loss of volar flexion	(<30°)	1
Loss of ulnar deviation	(<15°)	3
Loss of radial deviation	(<15°)	1
Loss of supination	(<50°)	2
Loss of pronation	(<50°)	2 *
Loss of circumduction		1
Pain in distal radio-ulnar joint		1
Gripstrength <60% of uninjured side		1 *
	score range	0-5
Complications		
Arthritic change	minimum	1
	minimum with pain	3
	moderate	2
	moderate with pain	4
	severe	3
	severe with pain	5
Nerve complications (median)		1-3
Poor finger function due to cast		1-2
	score range	0-5
End result score ranges		
Excellent		0-2
Good		3-8
Fair		9-20
Poor		>21

* Sarmiento's modification (162)

The degree of disability, resulting from decreased motion, is an important factor in evaluating the functional end result after Colles fractures. According to Swanson et al (185) and the Committee on Medical Rating of Physical Impairment (81), the degree of disability is equal in loss of dorsal flexion and volar flexion, equal in loss of ulnar deviation and radial deviation and equal in loss of pronation and supination. Loss of ulnar deviation and radial deviation gives 0.42 time the degree of disability as loss of dorsal flexion and volar flexion gives. These facts have not been considered in the various scoring systems.

In the evaluation of wrist injuries the uninjured wrist should serve as the individual standard because for practical purposes the left and right wrist are anatomical and functional bilaterally symmetrical (56, 71,134,157). The grip power however, is assumed to be 10% greater in the major hand (14,105,144). In many scoring systems, the uninjured side is not or only partly considered.

The ultimate purpose of treatment of distal radius fractures is to preserve normal function in the hand (115,159). However, hand function after Colles fracture is seldomly mentioned (115).

No system to evaluate the speed of functional recovery could be found.

3.11 End results

The functional end result can only be judged from one year post-injury (68,172). No reports were found indicating from which time onwards the anatomical end result can be assessed. The cosmetic end result seems to match generally with the anatomical result (73,86,109), although many cases of considerable anatomical deformity had no corresponding cosmetic impairment in Frykman's study (73). The use of different definitions, indications, criteria and scoring systems and the unequal populations makes comparison of treatment outcome in the various mostly retrospective studies very difficult or even impossible.

Sarmiento et al (159,162) compared results of their functional bracing in supination with retrospective studies of conventional plaster treatment. Although their method did not entirely prevent collapse of the fracture they concluded that the functional end result and anatomical end result are superior and that early function via functional bracing leads to early recovery of the range of motion and to a speedy rehabilitation. Bünger et al (26) published in 1984 a prospective study in which functional bracing in supination was compared to dorsal plaster splint immobilisation. After 6 months the anatomical and functional result obtained with functional bracing was significantly better than with immobilisation. The superior functional result was thought to be primarily due to the better anatomical result. Stewart et al (178) reported in 1984 results from a prospective study comparing functional bracing in supination, functional bracing with a below-the-elbow brace, and below-the-elbow plaster treatment. They found no significant difference in anatomical and functional result or occurrence of complications 6 months after the injury.

The end results from various studies are listed in Table 3.10.

Table 3.10 End results

End results of various studies of plaster cast treatment, functional treatment and skeletal fixation.

ref. nr.	technique	N	evaluation	follow up (yr)	results
Plaster cast treatment					
9	not mentioned	2132	own	4-14	average disability:24% loss of hand function
109	dorsal plaster ulnar deviation	515	Lid	3- 9	48% loss of motion 21% fair/poor functional result 37% moderate to severe anatomical deformity 40% unsatisfactory cosmetic result
74	dorsal and volar splints volar flexion ulnar deviation	60	G-W	1- 4	32% unsatisfactory functional result 60% unsatisfactory anatomical result

continuation Table 3.10

ref. nr.	technique	N	evaluation	follow up (yr)	results
73	dorsal plaster various positions	430	Lid	2- 5	25% fair/poor functional result 25% excellent anatomical result 52% subjective complaints 36% subjective weakness
17	dorsal plaster ulnar deviation pronation	93	Lid	1-1½	11% fair or poor functional result 65% excellent anatomical result
30	dorsal and volar splints, varying volar flexion	135	own	unknown	6% poor functional result 14% poor or bad anatomical result
175	primary ulna resection, dorsal plaster	42	own	¼	12% bad functional result 60% bad anatomical result
Functional treatment					
163	Sarmiento functional brace	104	G-W Lid	6-23 wk	10% fair or poor functional result 32% fair or poor anatomical result
159	Sarmiento functional brace	44	G-W Lid	short	18% fair or poor functional result 39% moderate or severe deformity
26	1. Sarmiento funct.brace 2. dorsal plaster ulnar deviation	145	G-W Lid	½	prospective study 1984 1. obtained significant better functional and anatomical result than 2.
178	1. Sarmiento funct.brace 2. dorsal plaster 3. below elbow funct.brace	243	G-W Lid	½	prospective study 1984 no significant difference in anatomical and functional result between the 3 methods
Skeletal fixation					
50	ulnar pinning	28	G-W	1-3	18% unsatisfactory functional result
56	ulnar pinning	51	G-W	¼-10	16% poor functional result
36	pins in plaster	33	G-W	1½-5	6% fair functional result 33% significant redislocation
164	pins in plaster	24	own	1-9	21% poor overall result 25% poor anatomical result 46% unsatisfactory grip test
79	pins in plaster	45	own	½-2½	14% unsatisfactory functional and anatomical results
43	Roger Anderson ext. fixation	60	own	2	15% fair or unsatisfactory subjective results. 10% fair or poor overall result
115	Rush rods	33	G-W	2½	3% poor functional result
122	Intern. fixation	15	various criteria	1-9	20% fair or poor subjective result 53% fair or poor objective result

Abbreviations:
own: author's own method of evaluation

Lid: lidströms classifications (109)
G-W: Gartland and Werley's score system(74)

3.12 Prognostic factors of the functional end result

- General factors

General factors like age and sex have no (76,109) or only very little (73) relationship to the functional end result. Bacorn and Kurtzke (9) however, regarded age to be an important prognostic factor.

- Fracture type

Comminuted fractures, intra-articular fractures especially through the distal radio-ulnar joint and ulnar styloid fractures seem to be associated with a poor prognosis (5,73,74,109,139). Sølund et al (172) noted a correlation between fracture type and duration of incapacity for work. Older et al (139) found that the prognosis of the functional end result can be predicted by the severity of the fracture at the time of injury.

- Anatomical end result

Controversy exists on the influence of the anatomical end result on the functional end result. Clinical observation, impression or just belief have frequently been used to assume an important influence (10,19,42,46, 67,86,131). A positive correlation between anatomical and functional end result is reported in some studies (17,30,31,76,109,196) but denied in others (56,175,197). Stewart et al (178,180) found in a prospective randomised trial six months after the trauma no correlation between functional end result (Gartland and Werley's system) and anatomical end result (Lidströms system). However, they found a clear correlation between the functional end result and the severity of the initial displacement. Bacorn and Kurtzke (9) claimed a correlation between externally visible residual deformity and disability. Their study is often used to conclude a causal relationship between anatomical and functional end result (36, 43,120,158). Wey et al (196) claimed that in 92% the function could be assessed from the final radiographs. However, many verified that a poor anatomical result does not preclude a good functional result and that a good anatomical result does not guarantee a satisfactory functional result (17,30,56,71,109,139,159,164,175,180). The influence of the residual volar angle shift, radial shortening and radial angle shift on the functional end result is also subject to controversial opinions (30,31, 73,74,115).

- Complications

The occurrence of major complications like Sudeck dystrophy, nerve injury and loss of radio-ulnar integrity are significantly associated with unsatisfactory functional results (73). Lippman (113) and Lidström (109) considered loss of radio-ulnar integrity the most common cause of poor functional results.

3.13 Conclusion and discussion

The Colles fracture is a frequent encountered injury with a rather high percentage of unfavourable end results and complications. Definition, classification, anaesthesia, reduction, method of treatment, management of the post-reduction period, evaluation of end results, treatment and definitions of the various complications are subject to different opinions. Little is published about minimally displaced fractures, compartment syndrome, soft tissue injury and speed of recovery. The most controversial aspect remains the fracture treatment. Many different methods have been advocated. These range from anatomical reduction and meticulous maintenance of the position to a full collapse of fracture fragments and from long immobilisation to early motion and function.

A central theme in the treatment is the influence of the anatomical end result on the functional end result. The authors' opinion on this is reflected in the chosen method of treatment. The influence however, remains usettled in literature. "Common sense" often is the only argument for the existence of a causal relationship between the anatomical and functional end result. If figures are reported, these reflect correlations found between the anatomical and functional result. Whether a positive correlation exists is still disputed. However, even if a positive correlation would exist, it is not justified to conclude that in that case a causal relationship exists as well. Since both items might depend on mutual factors like severity of the injury, type of fracture, fracture reduction and age, a positive correlation can be found without the existence of a causal relationship. This means that changing the anatomical result will not then alter the functional result despite a positive correlation. No efforts have been made to really investigate a causal relationship between the anatomical and functional end result.

The most frequently used scoring systems to evaluate end results are unsatisfactory because the uninjured side is not or only partly used as the individual standard, important parameters are not defined, point scales do not correspond with the guidelines of the Committee on Medical Rating of Physical Impairment (81), hand function is not considered, and the final graduations are arbitrary.

It is difficult to estimate the value of the various different methods of treatment, including functional bracing, as comparison of results from the literature seems almost impossible and only very little well documented comparitive prospective clinical studies have been performed.

CHAPTER 4
DESIGN OF THE STUDY

In the design of a study aiming to establish the application field of functional treatment of Colles fractures by comparing results from this kind of treatment with conventional below-the-elbow plaster treatment, first the type(s) of functional treatment to be used in the study should be determined. Various degrees of early motion and function are possible. Too much early motion and function however, might result in redislocation of initially reduced fractures and thus in a bad anatomical result. Most likely, this will happen more frequently in unstable fractures than in stable fractures. If a strong causal relationship exists between the anatomical and functional end result, the degree of early motion and function is rather restricted as redislocation should be prevented. On the other hand, if no strong causal relationship exists, more early motion and function can be tolerated as a possible redislocation is hardly detrimental for the functional end result. The study focusses on that optimal early motion and function in which the possible advantage of functional treatment is not undone by disadvantages resulting from reduced stabilisation. Fracture stability and the kind of relation between anatomical and functional result appear to be important items in the search for this optimal early motion and function. Whether the optimal early motion and function varies with the fracture stability, needs to be investigated. The existence of a causal relationship between anatomical and functional end result has not been settled up to now; this needs investigation as well. A proper methodological way to investigate the existence of a causal relationship would be to study the correlation between anatomical and functional end result in a clinical experiment in which the anatomy is manipulated while all other important unfluential factors are kept constant. However, such an experiment is not possible on ethical grounds. Another way to investigate the existence of a causal relationship is to evaluate the correlation between anatomical and functional end result while the influence of other important factors is kept constant by means of statistical analytical methods. This is possible and performed in this prospective clinical study.

At the start of this study (1981) Sarmiento's functional bracing in supination was the only reported type of functional treatment of Colles fractures. Another type of functional treatment described in 1984 (178) could not be implemented in this study. Sarmiento's method is propagated regardless of the fracture stability. Although early volar flexion and ulnar deviation are permitted, pronation and supination are restricted. This is in contrast to conventional below-the-elbow plaster treatment that does not fully restrict pronation and supination. In this respect, the conventional treatment is even slightly more functional than Sarmiento's method. To fulfil the aim of the thesis, a logical first step is to compare Sarmiento's functional bracing in supination with below-the-elbow plaster treatment. If no contra-indications are found, functional bracing with more early motion and function needs to be tested in a second step as well. Based on the above mentioned considerations, a logical choice in that case is to permit, besides early volar flexion and ulnar deviation, some pronation/supination as well. In addition for minimally displaced fractures a method can be investigated that does not restrict any motion at all. This choice is based on the fact that minimally displaced fractures are not reduced and are generally regarded to be stable, and on the assumption that if the trauma does not result in gross anatomical displacement, it is not very likely that early motion and function will do. Whether still another type of functional treatment needs to be tested depends on the results from the first two investigation phases and on the outcome of the investigation on the causal relationship between anatomical and functional end result.

In retrospective studies, Sarmiento claimed a faster functional recovery and a better functional and anatomical end result with his method, compared to conventional plaster treatment (Paragraph 3.11). Therefore, in this prospective study, both the speed of functional recovery and the functional end result are used as a criterium for treatment outcome comparison. The anatomical end result is not used as a criterium because the causal relationship between the anatomical and functional end result is unrevealed. Different methods of treatment might lead to different complications. Therefore, the occurrence of complications is added as a criterium for comparison of treatment outcome.

As the common score systems to evaluate the functional results are unsatisfactory (Paragraph 3.13), and no system to evaluate the speed of functional recovery was found in literature, another system is developed for this study.

In the literature many aspects of the Colles fracture lack commonly accepted definitions. In this study the following definitions are used:

<u>Colles fractures:</u>
An injury of the forearm and wrist resulting in a complete transvers break of the distal 3 cm of the radius in adults, with dorsal displacement and/or dorsal angulation of the distal fragment or without displacement of fragments

<u>Minimally displaced fractures:</u>
A Colles fracture with a volar angle of 0^{o} or more (i.e. without dorsal angulation)

<u>Anatomical result:</u>
The volar angle, radial angle and radial length difference between injured and uninjured side and the radial shift

<u>Initial displacement:</u>
The anatomical result after the trauma

<u>Quality of reduction:</u>
The anatomical result after reduction

<u>Anatomical end result:</u>
The anatomical result one year after the trauma

<u>Functional result:</u>
The score of the evaluation system used in this study, reflecting the patients disability

<u>Functional end result:</u>
The functional result one year after the trauma

<u>Functional recovery:</u>
The improvement of the functional result during the first year

Based on the previous reflexions the following hypotheses were formulated:

Hypothesis 1
Functional treatment of Colles fractures with Sarmiento's functional bracing in supination is superior to conventional plaster treatment according to the following criteria:
- faster functional recovery
- better functional end result
- less complications

If results of a clinical study testing hypothesis 1 do not indicate inferior results of Sarmiento's functional bracing over conventional plaster treatment, hypothesis 2 and 3 will be tested as well:

Hypothesis 2
In displaced fractures, functional treatment with a below the elbow functional brace that restricts dorsal flexion and radial deviation is equal or superior to Sarmiento's functional bracing and conventional plaster treatment according to the above mentioned criteria.

Hypothesis 3
In minimally displaced fractures, functional treatment with a bandage is equal or superior to Sarmiento's functional bracing and conventional plaster treatment according to the above mentioned criteria.

Hypothesis 4
A causal relationship exists between the anatomical end result and functional end result.

These hypotheses were worked out in a prospective clinical study as described in the next chapter.

CHAPTER 5
METHODS

5.1 Patients
From October 1981 till May 1983, all patients with a Colles fracture and united epiphyseal plates treated in the Department of General Surgery of the University Hospital Maastricht, The Netherlands, entered the study.
Exclusion criteria were:
- accompanying other fracture of the same limb
- open fracture
- a fracture older than 3 days
- bilateral fractures
- multitrauma injury
- previous fractures of the same limb
- pre-existing impairment of the same limb
- continuation of treatment elsewhere

Withdrawal criteria were:
- mental or physical unability to cooperate
- persisting volar angle $<-5^o$ after reduction
- more than two missed follow ups

5.2 Clinical trials
The study consisted of two clinical trials:

1. Patients were allocated into two different treatment groups:
   - "Conventional" or "CON", treated with a conventional below-the-elbow plaster splint.
   - "Sarmiento" or "SAR" treated with Sarmiento's brace in supination.

   The allocation criterium was odd or even day on the first visit. One year after the start, provisional results in the Sarmiento group appeared slightly better than in the conventional group. To complete the next step in the research design, the second clinical trial started.

2. Patients were allocated into the following two groups:
   - "Sarmiento" or "SAR", treated with Sarmiento's brace in supination.
   - "Functional" or "FUN": displaced fractures were treated with a functional below-the-elbow brace restricting dorsal flexion and radial deviation; minimally displaced fractures were treated with a bandage.

   In the second trial, numbered forms in the sequence three times functional, one time Sarmiento, were used for the patient allocation. (In this way, the total in the Sarmiento group would not become too large.)

As a result of the two clinical trials, three groups of differently treated patients were formed.

5.3 Initial management

The initial management was performed by the surgical resident on duty. The diagnosis was made on clinical suspicion and radiographic confirmation. Circulation, nerve function, skin integrity and accompanying injuries were checked. Based on Sarmiento's fracture classification, two kinds of fractures were distinguished; displaced (Type 2 and 4) and minimally displaced (Type 1 and 3) fractures. Displaced fractures were intrafocally anaesthesised with 10 ml lidocain 2%. Subsequently traction was applied for 15 minutes with chinese fingertraps and a weight of 4 kg pulling a sling over the upperarm. Reduction was performed in pronation (Figure 5.1). The criterium for adequate reduction was a volar angle of 0^o or more. If inadequate, reduction was tried only once more; if a volar angle less than -5^o was obtained, the patient was excluded from the study. Minimally displaced fractures were not reduced.

In the conventional group all patients were treated with a below-the-elbow dorsal plaster splint with the wrist in slight flexion and slight ulnar deviation. Pronation and supination were not completely restricted as the cast did not extend above the elbow (Figure 5.2).
In the Sarmiento group all cases were treated initially with an above-the-elbow dorsal plaster splint with the forearm in supination and the elbow in 90^o flexion (Figure 5.3).
In the functional group all patients were treated initially with the same below-the-elbow dorsal plaster splint as in the conventional group (Figure 5.2).
All patients received information concerning the injury an instruction on exercises both verbally and by means of a printed form (Addendum 1).

5.4 Management in the post reduction period

One day after the initial management, all patients returned for a plaster check up. If too tight, the plaster was adjusted. 6 to 9 days after the trauma, all patients attended the outpatient clinic:
In the conventional group the below-the-elbow plaster splint was left in situ for another 3 weeks. A new bandage was applied over the splint to correct for loosening due to decreased swelling. This was repeated one week later.
In the Sarmiento group the above-the-elbow plaster splint was changed for an above-the-elbow functional brace with the forearm in supination. During this procedure, continuous traction was applied by chinese fingertraps and a weight pulling the humerus. Dorsal flexion, radial deviation and pronation were restricted. The last 45^o elbow extension was also restricted. Volar flexion and ulnar deviation were unrestricted (Figure 5.4).
In the functional group all patients with displaced fractures got their below-the-elbow plaster splint changed for a below-the-elbow functional brace. The changing procedure was performed as in the Sarmiento group. The brace restricted dorsal flexion and radial deviation; volar flexion, ulnar deviation, pronation and supination were not restricted (Figure 5.5). All patients with minimally displaced fractures were treated with a bandage after removal of the plaster splint. The bandage allowed motion in all directions (Figure 5.6).

Figure 5.1 Anaesthesia and reduction

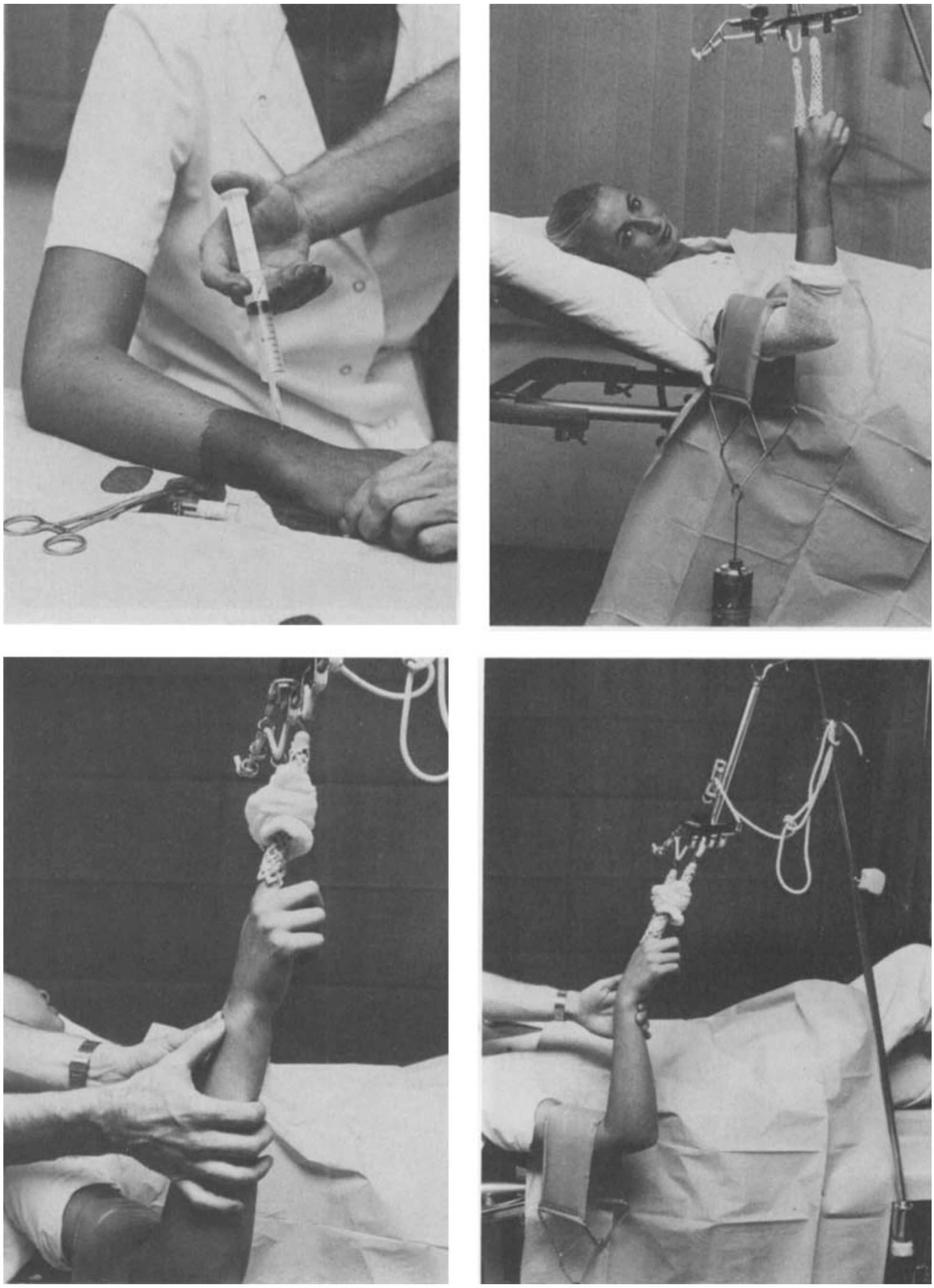


Figure 5.2 Conventional below-the-elbow plaster splint

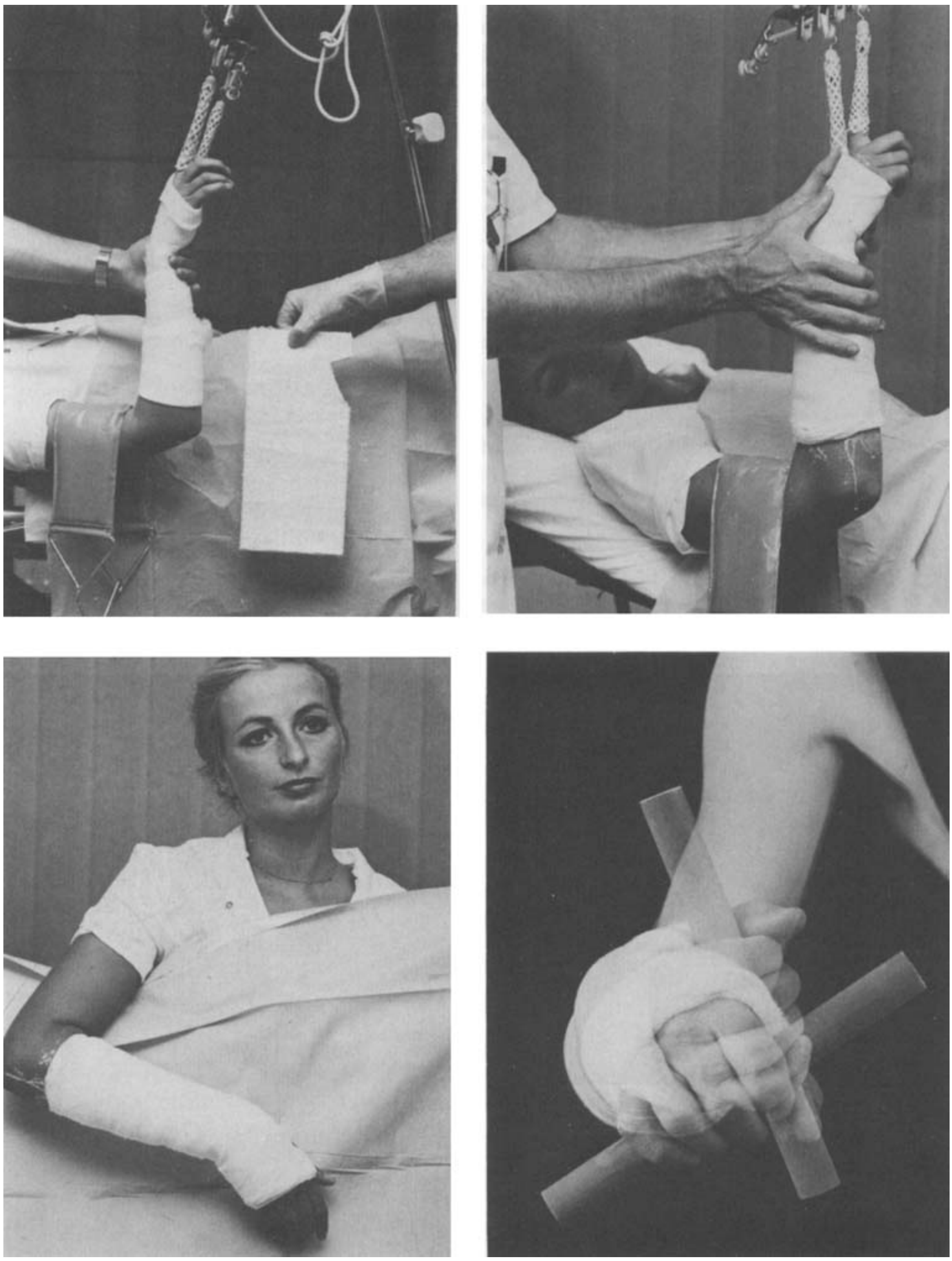


Figure 5.3 Above-the-elbow plaster splint with the forearm in supination

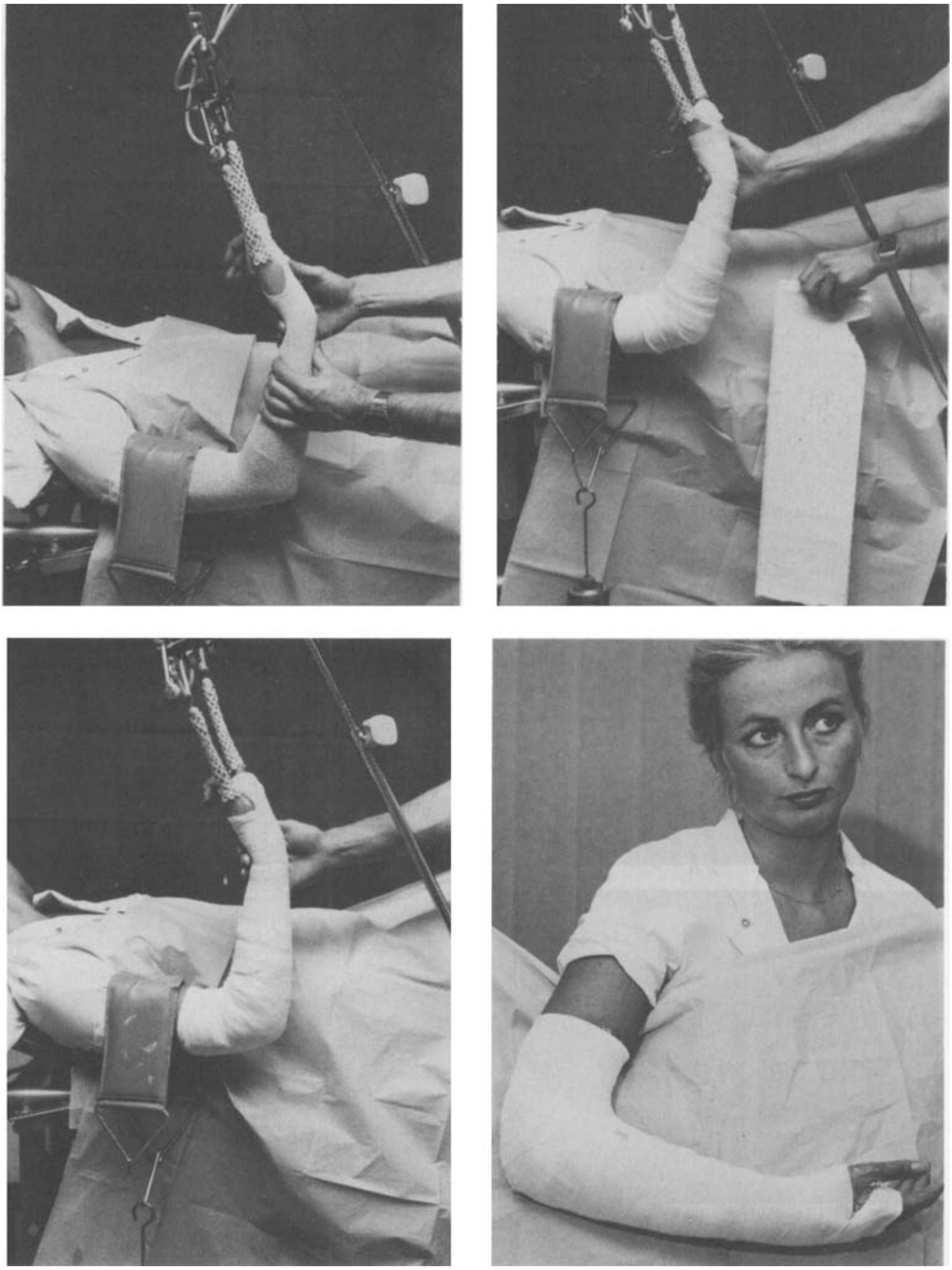


Figure 5.4 Sarmiento's above-the-elbow brace

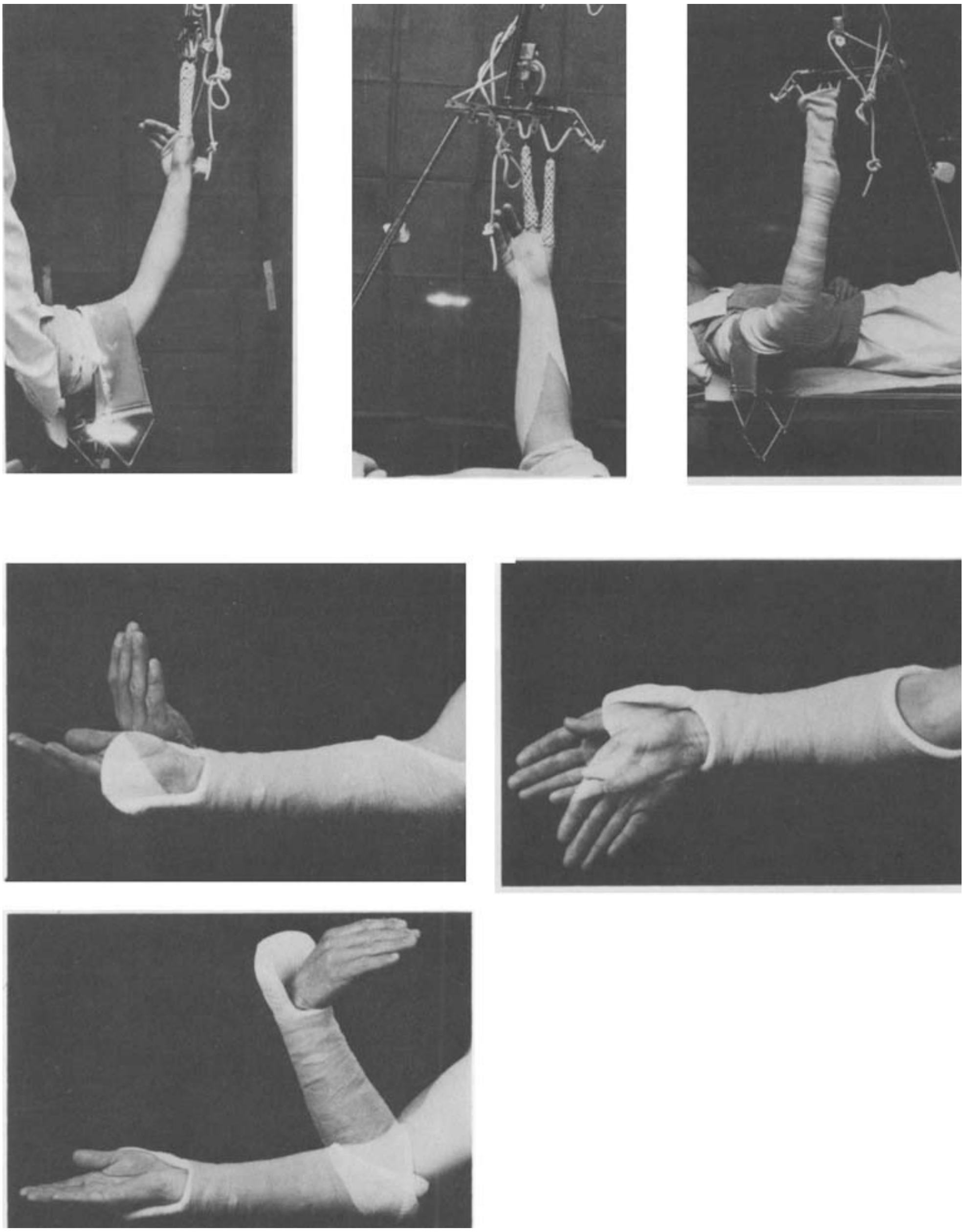


Figure 5.5 Functional below-the-elbow brace

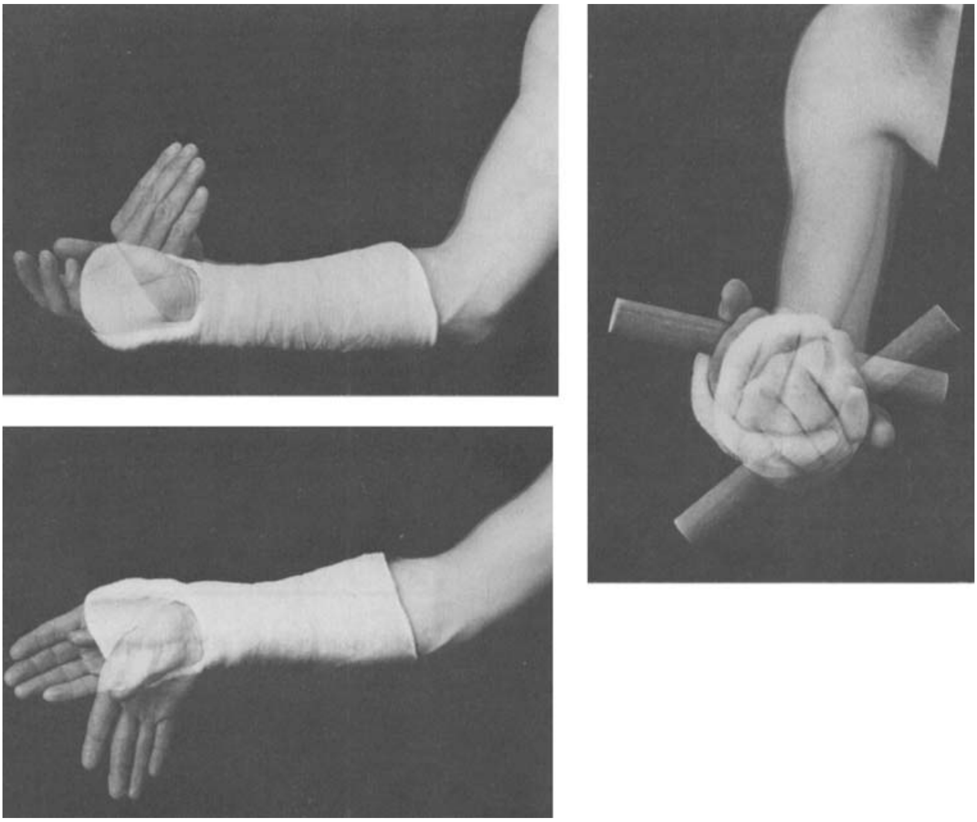
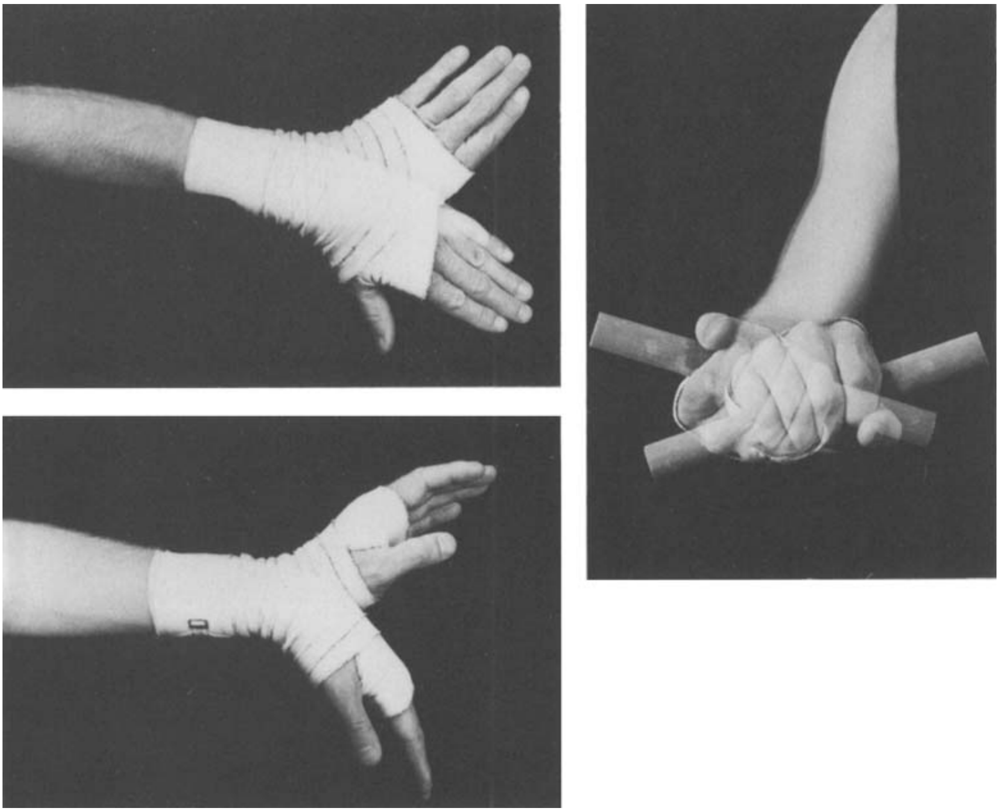


Figure 5.6 Bandage technique



Cellona® plaster of Paris was used for the plaster splints. The "Sarmiento" and the "functional" brace were made of Baycast®. This material was selected because it is light, which is important to facilitate early motion and function. Tensoplast® adhesive strappings were incorporated in the braces and fixed to the skin to prevent shifting (Figure 5.4). Patients in the Sarmiento group and functional group received new instructions on exercises, verbally and on a printed form (Addendum 2). Patients in the conventional group were advised to continue their original exercises.

Information was obtained on the dominant hand, profession, and on possible previous fractures and impairment of the upper extremities.

One and two weeks post-trauma, radiographs of the injured wrist were made to check the position. Rereduction was performed if redislocation resulted in a volar angle less than -10^{o} or a radial angle more than 15^{o} different from the uninjured side (radiographs of the uninjured wrist were made one week post-trauma). The rereduction was performed by suspending the arm by means of chinese fingersplints after i.v. diazepam medication. After the rereduction the same treatment device as before the procedure was applied.

The management in the post reduction period was carried out by the author.

The treatment during the first 4 weeks is outlined below:

Group	1 week	3 weeks	Possible motion
conventional	plaster splint below-the-elbow	plaster splint below-the-elbow	pronation / supination
Sarmiento	plaster splint above-the-elbow in supination	functional brace above-the-elbow in supination	volar flexion ulnar deviation
functional	plaster splint below-the-elbow	displaced: functional brace below-the-elbow	volar flexion ulnar deviation pronation / supination
		minimally displaced: bandage	all motions

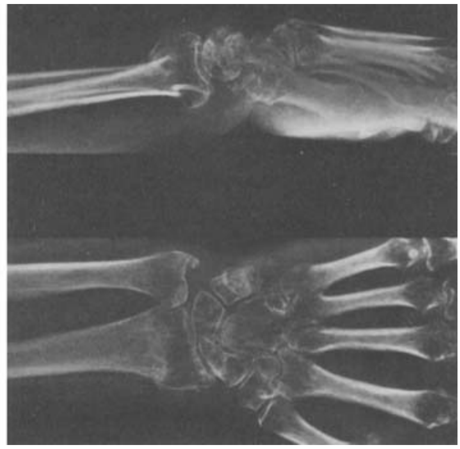
5.5 Management in the rehabilitation period
Four weeks (28-31 days) after the trauma, the plaster, brace or bandage was removed in all cases and instructions were given verbally and in writing to perform exercises (Addendum 3). If motion and/or grip power appeared less than 1/3 of the uninjured side at 6, 10 or 14 weeks post-trauma, physiotherapy was prescribed, consisting of ultrasound, fango and active exercises without causing pain. The outpatient department was attended at scheduled checkpoints; 4 weeks, 6 weeks, 10 weeks, 14 weeks, 26 weeks and 1 year after the trauma. At these checkpoints complications were dealt with and data were recorded, necessary for the study (Paragraph 5.6, 5.7). The management in the rehabilitation period was carried out by the author.

5.6 Diagnosis and management of complications
1. complications due to cast or brace
Pressure sores and abrasions when encountered at the outpatient clinic were treated by adjustment of the plaster cast or brace and wound dressing. Shifted braces were replaced and refixed to the skin.
2. redislocation needing rereduction is discussed in Paragraph 5.4.
3. nerve injury
The diagnosis was based on EMG-studies. Indication for EMG was numbness and/or paraesthesia in the hand, appearing after the injury and existing for four weeks. If nerve compression was diagnosed, no treatment was given during the following four weeks. If the complaints still remained, operative decompression was performed. If the complaints disappeared in the last four weeks or if the patient refused treatment, no operation was performed. Signs of nerve compression immediately after the accident were never found.

4. tendon injury
The function of the finger tendons was tested at every checkpoint from 4 weeks onwards. Rupture of the extensor pollicis longus tendon (Figure 5.7) was treated by indicis proprius tendon transfer. Stenosing tendosynovitis was treated with two local corticosteroid injections. If unsuccessful, operative release was performed.

Figure 5.7 Spontaneous rupture extensor pollicis longus tendon

Figure 5.8 Sudeck dystrophy



5. Sudeck dystrophy
Sudeck dystrophy is a rather vague entity. To standardise the diagnosis if the three stages of Sudeck dystrophy, the following criteria were chosen, which were based on Table 3.5 :
Stage 1: if three or more of the following symptoms were present: pronounced pain, swelling, hyperemia, hyperaesthesia, hyperhidrosis, restriction of motion less than 1/3 of the non-injured wrist.
Stage 2: if besides skin atrophy or polar demineralisation of the bone (Figure 5.8), two or more at the above mentioned symptoms were found.
Stage 3: a pale, stiff hand with dry skin and diffuse demineralisation. This stage was not encountered.
Treatment in stage 1 and 2 consisted of active physiotherapy without causing pain and analgetics.
6. Loss of radio-ulnar integrity
The diagnosis was based on one or more of the following symptoms:
- persistant tenderness and compression pain over the distal ulna and radio-ulnar joint at 26 and 52 weeks.
- pain during pronation, supination and ulnar deviation at 26 and 52 weeks.
- a click or block while rotating.
- laxity of the distal radio-ulnar joint.

Loss of radio-ulnar integrity, disturbing the patient, was an indication for resection of the distal ulna.
7. Post-traumatic arthritis
This complication was defined by sclerosis of joint surfaces, subchondral clearing or formation of osteophytes present on radiographs one year after the trauma while absent on the initial radiographs.

8. Loss of motion
The diagnosis was made if dorsal flexion, volar flexion, radial deviation, ulnar deviation, pronation or supination appeared less than 2/3 of the un-injured side, one year post-trauma.
9. Dupuytren's disease
The diagnosis was based on the development of palmar nodules and bands. Although Dupuytren's disease was found in some cases, no contractures developed during the study and no treatment was given.

The complications post-traumatic arthritis and loss of motion were diagnosed at the end of the study. Therefore, the management and treatment are not discussed in this chapter.

5.7 Parameters
During one year follow-up, parameters were scored or measured in a standardised way to evaluate results of the study. These parameters were selected from the review of literature and from tests of daily life activities. In Table 5.9, the follow-up schedule of the parameters is indicated; the "complaints" were recorded through a standardised questionaire. The "motion in the wrist region" was recorded with an angle goniometer and a specially designed rotation goniometer (Figure 5.10). The "motor functions of the hand" were assessed by a series of standardised tests. The criteria for making a fist, finger extension and opposition were respectively: touching the palm of the hand, full extension to 0^o and touching the little finger with the thumb. The grip power was measured with a Jamar hand dynamometer as adviced in the literature (14,102). The "signs and symptoms" were scored by comparison with the uninjured side. The scorig of the "cosmetic appearance" was based on Lidströms classification (Paragraph 3.10). The "radiographic parameters" were measured with a specially designed measurement device (Figure 5.11).

Figure 5.10 Rotation goniometer

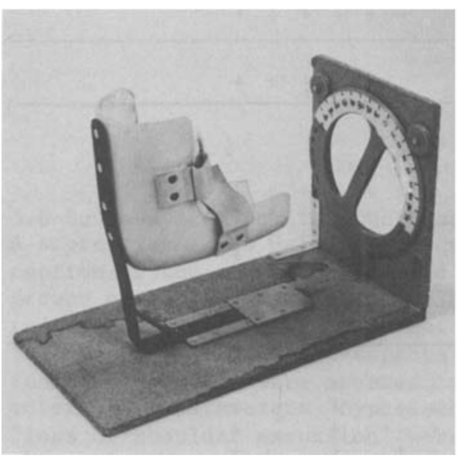


Figure 5.11 Radiographic parameter measurement device

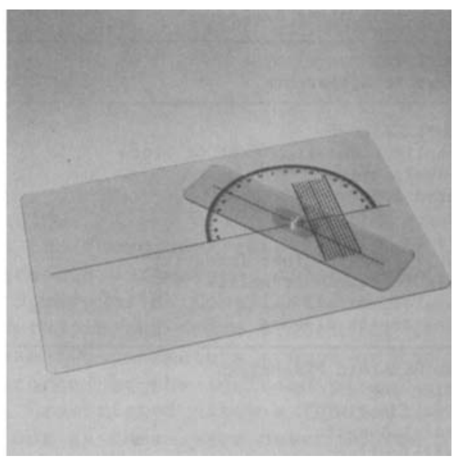


Table 5.9 Follow-up schedule of parameters

	day		week							
time	0	1	1	2	4	6	10	14	26	52
COMPLAINTS										
pain while resting		+	+	+	+	+	+	+	+	+
pain while moving			+	+	+	+	+	+	+	+
pain during heavy work/excessive motion			+	+	+	+	+	+	+	+
numbness or paraesthesiae in the fingers		+	+	+	+	+	+	+	+	+
restricted basic daily life activities			+	+	+	+	+	+	+	+
no resumption of daily work			+	+	+	+	+	+	+	+
pain while wringing clothes							+	+	+	+
loss of power							+	+	+	+
subjective judgement of the end result									+	+
open question for complaints		+	+	+	+	+	+	+	+	+
MOTION IN THE WRIST REGION										
dorsal flexion					+	+	+	+	+	+
volar flexion					+	+	+	+	+	+
radial deviation					+	+	+	+	+	+
ulnar deviation					+	+	+	+	+	+
supination					+	+	+	+	+	+
pronation					+	+	+	+	+	+
MOTOR FUNCTIONS OF THE HAND										
grip power					+	+	+	+	+	+
making a fist			+	+	+	+	+	+	+	+
finger extension					+	+	+	+	+	+
opposition			+	+	+	+	+	+	+	+
opening a door					+	+	+	+	+	+
weight lifting					+	+	+	+	+	+
picking up a pen					+	+	+	+	+	+
crumpling a piece of paper					+	+	+	+	+	+
lifting a cup and saucer					+	+	+	+	+	+
SIGNS AND SYMPTOMS										
swelling of hand/fingers		+	+	+	+	+	+	+	+	+
abormal colour		+	+	+	+	+	+	+	+	+
skin atrophy/hyperaesthesia/hyperhidrosis					+	+	+	+	+	+
hypoaesthesia	+	+	+	+	+	+	+	+	+	+
ulnar compression pain					+	+	+	+	+	+
restricted elbow extension					+	+	+	+	+	+
loss of shoulder excursion					+	+	+	+	+	+
COSMETICS										
cosmetic appearance								+	+	+
COMPLICATIONS										
complications from cast or brace		+	+	+	+					
redislocation			+	+						
nerve injury	+	+	+	+	+	+	+	+	+	+
tendon injury					+	+	+	+	+	+
Sudeck dystrophy					+	+	+	+	+	+
loss of radio-ulnar integrity						+	+	+	+	+
post traumatic arthritis										+
loss of motion										+
Dupuytren's disease									+	+
RADIOGRAPHIC PARAMETERS										
volar angle	+		+	+	+		+			+
radial angle	+		+	+	+		+			+
radial length	+		+	+	+		+			+
radial width	+		+	+	+		+			+

Table 5.12 Score system for the functional result

			score	
COMPLAINTS				
a. pain while resting			10	
b. pain while moving			8	
c. pain during heavy work/excessive motion (if b=0)			4	
d. numbness or paraesthesiae in the fingers			3	
e. restricted basic daily life activities			10	
f. pain while wringing out clothes (if b+c=0)			3	
g. loss of power			3	
h. subjective judgement of the end result			5 or 10	
i. open question for complaints (if a+b+c+h=0)			1 or 2 or 3	
MOTION IN THE WRIST REGION	0-40%	40-60%	60-80%	80-90%
dorsal flexion	5	4	3	2
volar flexion	5	4	3	2
radial deviation	2	1	1	0
ulnar deviation	2	1	1	0
pronation	5	4	3	2
supination	5	4	3	2
MOTOR FUNCTIONS OF THE HAND	0-40%	40-60%	60-80%	80-90%
grip power	8	5	3	2
making a fist			8	
finger extension			8	
opposition			8	
	abnormal		impossible	
opening a door	5		8	
weight lifting	5		8	
picking up a pen	5		8	
crumpling a piece of paper	5		8	
lifting a cup and saucer	5		8	
SIGNS AND SYMPTOMS				
swelling of hand/fingers			5	
abnormal colour			2	
skin atrophy/hyperaesthesia/hyperhidrosis			4	
ulnar compression pain			2	
COSMETICS				
cosmetic appearance			2 or 3 or 5	

5.8 Score system for the functional result.

A score system was designed to evaluate the functional result. With exception of the complications and radiographic parameters, all other groups of parameters listed in Table 5.9 were used. Complications and radiographic parameters were not considered in the score system for the functional result as the effects of these two parameters groups on the functional result were assumed to be recorded by the included parameters. The parameters "hypoaesthesia", "restricted elbow extension" and "loss of shoulder excursion" were left out as these were never scored as abnormal. The penalty score assigned to parameters as shown in Table 5.12 was based on the guidelines of the Committee on Medical Rating of

Physical Impairment (81) and on the opinion of some prominent traumatologists in the Netherlands. The uninjured wrist served as the normal standard. Grip power of the dominant hand was assumed to be 110% of the non-dominant side. "Subjective judgement of the end result" was scored 5 if the patient complained of impaired function only during heavy work or extraordinary movement; the score was 10 in case of impaired function during daily activities or affected general way of life. "Open question for complaints" was the only parameter to which the penalty scores were assigned at the end of the study; 1 for complaints of sometimes prickling, itching, cold/stiff fingers or aching during change in weather; 2 in case of blocking or clicking wrists, stiff joints, burning sensation, inability to use a vacuum cleaner, carrying heavy objects or limitation of motion in one direction; the score was 3 for complaints of limitation of pulling, pushing, lifting heavy objects or limitation of wrist motion in more than one direction. "Cosmetic appearance" scored 2 in case of a prominent ulnar head, slight radial deviation, swelling or broadening of the wrist; 3 for a combination of aforementioned findings and 5 when a pronounced radial deviation or dinnerfork deformity was found.

5.9 Fracture classification

Sarmiento's fracture classification (Figure 3.4) was used to determine the type of fracture, necessary for data analysis in this study. This classification system was selected as it is simple and includes fracture stabilty. Minimally displaced fractures were classified as Type 1 or 3. (Figure 5.13) This small modification was performed as it appeared that almost all "non-displaced fractures" still showed some slight displacement. The fracture characteristics "radio-ulnar joint involvement" (criterium: fracture towards ulnar head) and "ulnar styloid fracture" from Frykman's fracture classifications (Figure. 3.3) were also used in this study for analytic purposes.

5.10 Statistical analysis

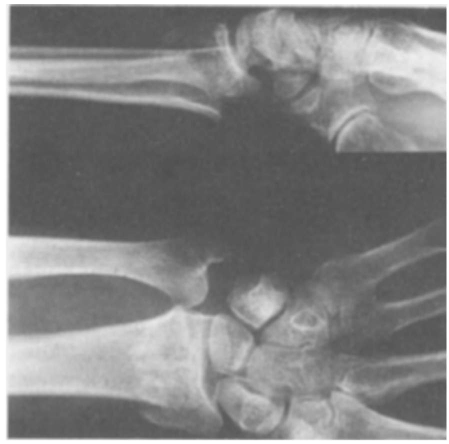
A possible weakness in the design of the study is the patient allocation (Paragraph 5.2). After careful consideration it was concluded that "pseudo-random" alternative day or subsequent patient-form assignement would be preferable to possible non compliance and uncontrollable use of a random assignment technique in a sometimes hectic 24-hours working casualty departement with frequent alternation of staff without continuous administrative support of the study.

At the start of the study it appeared difficult to assess the sample size. Important information to apply power calculation was absent, like the minimally clinical important treatment difference, the level of response of the standard treatment and estimation of the variance. Experience with or numerical results of the specially designed score system for the functional result were not available. Numerical results of other score systems used in comparable studies were nonexistent, inadequate or non transposable. To guarantee 80% power for detecting a difference in mean response of half a standard deviation at the 5% significance level, a sample size of approximately 60 patients in each group was chosen. Expecting large interpatient variability a difference in mean value of half a standard deviation between treatment groups was thought to be of possible clinical interest.

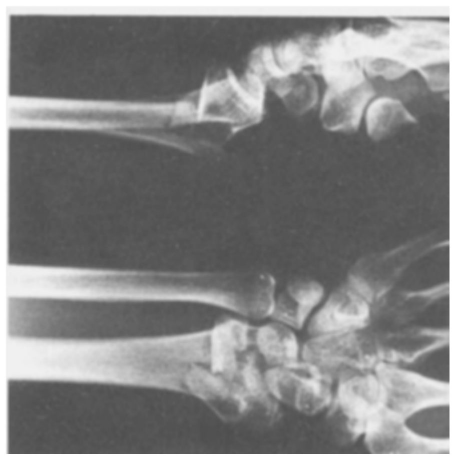
Figure 5.13 Sarmiento's fracture classification

Type 1

Type 2



Type 3



Type 4

In the study standard statistical techniques were used like analysis of variance, chi-square tests, t-tests and the Kruskall-Wallis test. In the analyses of variance the results of the F-tests for main effects are sometimes supplemented with t-tests for treatment and/or subgroup contrast to indicate the treatment groups or subgroups responsible for the difference indicated by a significant overall F-test. The significant level adopted for testing main effects was the 5% level. When testing contrasts a more stringent level was used to guard against the added risk of false-positive results induced by multiple hypotheses testing. As a visual aid to the reader, all p-values for main effects smaller than 5% and all "significant" contrast test results were starred(*). Statistical analysis sometimes was done additionally as a check on transformed data to obtain better approximations to the assumptions necessary for use of the statistical techniques. When only transformed data were analysed, the results are reported for the transformed date; in all other cases, the results are reported for the original non transformed data. Other statistical techniques used in this study were regression analyses and techniques for the analysis of linear structural relation models based on the program LISREL (93).

In order to assess the measurement error of some parameters, the wrists and hands of 10 healthy persons were subjected to measurements on five subsequent occasions. The results are listed in Table 5.14. The percentage of total variance and the tolerance intervals for the absolute error $\Delta = x - \mu$ are indicated. The tolerance interval encloses 90% of all potential absolute errors of measurement with 95% probability, which means that the difference between the actual value and at least 90% of the measurements will be less than the number indicated in the table, with a probability of 95%. The results indicate that the measurement errors were not great. The measurement error of radiograph parameters was not calculated as the differences between various measurements of the same radiographs were very small. This indicates that an error of radiographic measurements hardly existed.

In the statistical analysis often less than 100% of the population of the concerned patient group was considered. This was due to the fact that in a few patients the uninjured wrist could not serve as the standard for comparission to calculate the functional result or anatomical result because of previous injuries. Other reasons were some lost radiograps and the fact that not all patients attended all checkpoints. In most tables the number of subjects per cell is not indicated as this would have made these tables unnecessarily cluttered. The approximate number of subjects per cell however, can always be deduced from the preceding more elementary tables.

Table 5.14 Measurement errors

The percentage of total variance (T.V.) with the standard deviation (S.D.) and the upper 90% tolerance limit (T.L.) of the measurement errors of motions in the wrist region and grip power.

	T.V.	S.D.	T.L.
dorsal flexion	3.8%	2%	4.09
volar flexion	37.2%	13%	4.79
radial deviation	36.1%	13%	5.64
ulnar deviation	27.0%	11%	3.85
supination	7.3%	4%	8.21
pronation	7.8%	4%	6.00
grip power	10.8%	5%	5.77

CHAPTER 6
PATIENT POPULATION

248 Patients entered the clinical study. 52 patients were excluded or withdrawn (Table 6.1). The total number of participating patients was 196, predominantly elderly women (Table 6.2-6.4, Figure 6.5).

The right wrist was slightly more affected than the left (Table 6.6). The most frequent fracture type was the displaced fracture without radio-carpal joint involvement (Type 2), followed by the displaced fracture with radio-carpal joint involvement (Type 4). Of the minimally displaced fractures, Type 1 was more frequent than Type 3 (Table 6.7). Ulnar styloid fracture as well as radio-ulnar involvement was encountered just under half of the cases (Table 6.8).

The initial displacement showed a wide range of values, which was more pronounced in displaced than in minimally displaced fractures (Table 6.9-6.12). The avarage reduction did not result in a position close to the original anatomy (Table 6.13).

In the above mentioned data, no statistically significant differences between the three treatment groups were found with exception of the right-left distribution and presence of ulnar styloid fracture (Table 6.6., 6.13).

The normal anatomy and normal motion in the wrist region as measured from the uninjured side, showed a large range of normal values (Table 6.14, 6.15).

Table 6.1 Exclusion and withdrawal from participation

Reason for and number of excluded or withdrawn cases.

	CON	SAR	FUN	total *
other than Colles type of distal radius fracture	4	5	1	10
accompanying other fracture of the same limb		2		2
multi-trauma injury	1	1		2
previous fracture of the same limb	3	1	1	5
pre-existing impairment of the same limb	6	2	2	10
continuation of treatment elsewhere	1			1
mentally or physically unfit for cooperation	3	4	1	8
persisting volar angle <-5^{o} after reduction			2	2
more than two missed follow ups	2	3	2	7
ommission of reduction in displaced fracture	1			1
error in allocation procedure	1	2		3
refusion of necessary reduction		1		1
total number	22	21	9	52
percentage of the group	21%	24%	16%	21%

*CON : conventional group
SAR : Sarmiento group
FUN : functional group

Table 6.2 Number of patients

Number and percentage of patients that participated in the clinical study.

	n	%
CON	82	42
SAR	67	34
FUN	47	24
total	196	100

Table 6.3 Female - male ratio

Number and percentage of female and male patients.

	female		male	
CON	58	71%	24	29%
SAR	58	87%	9	13%
FUN	36	77%	11	23%
total	152	78%	44	22%

chisquare test p = 0.07

Table 6.4 Age distribution

Number and percentage of patients in subsequent age intervals in each group.

years	11-20		21-30		31-40		41-50		51-60		61-70		71-80		>80	
CON	2	2%	8	10%	5	6%	9	11%	24	29%	22	27%	9	11%	3	4%
SAR	1	1%	6	9%	4	6%	6	9%	17	25%	18	27%	7	10%	8	12%
FUN	1	2%	1	2%	5	11%	4	9%	7	15%	15	32%	10	21%	4	9%
total	4	2%	15	8%	14	7%	19	10%	48	25%	55	28%	26	13%	15	8%

chisquare test p = 0.51

Figure 6.5 Age distribution for female and male

Percentage of the total number of female and male patients in subsequent age intervals.

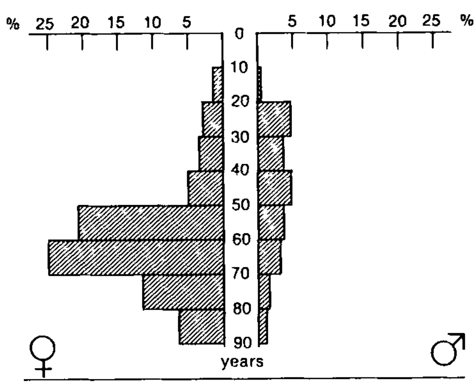


Table 6.6 Right-left distribution

Side of injury, number and percentage.

	right		left	
CON	46	56%	36	44%
SAR	41	61%	26	39%
FUN	16	34%	31	66%
total	103	53%	93	47%

chisquare test p = 0.01*

table 6.7 Fracture type distribution

Number and percentage of patients in the four groups of different fracture types.

	T1		T2		T3		T4	
CON	19	23%	34	41%	8	10%	21	26%
SAR	11	16%	31	46%	4	6%	21	31%
FUN	10	21%	23	49%	3	6%	11	23%
total	40	20%	88	45%	15	8%	53	27%

chisquare test p = 0.83

Table 6.8 Ulnar styloid fracture and radio-ulnar joint involvement

Number and percentage of fractures accompanied by an ulnar styloid fracture (US) and by radio-ulnar joint involvement (RU).

	US		RU	
CON	46	56%	38	46%
SAR	24	36%	28	42%
FUN	18	38%	19	40%
total	88	45%	85	43%
chisquare test p =	0.03*		0.77	

Table 6.9 Initial volar angle difference

Mean, standard deviation (sd), maximum (max) and minimum (min) value of the initial volar angle difference (V1) of all fracture types (T1234) and of the four different types.

		T1234	T1	T2	T3	T4
CON	mean	22.86	5.32	33.59	4.17	31.50
	sd	17.50	4.81	14.57	5.91	12.41
	max	74	15	74	15	48
	min	-1	-1	11	-1	7
SAR	mean	26.66	3.00	33.28	3.25	35.67
	sd	17.96	5.16	12.34	2.22	15.44
	max	62	15	62	5	60
	min	-2	-2	11	0	10
FUN	mean	26.73	6.78	34.19	7.00	34.18
	sd	16.34	5.63	12.08	10.44	12.47
	max	61	17	61	19	51
	min	-1	-1	1	0	19
total	mean	25.17	5.00	33.64	4.54	33.72
	sd	17.39	5.16	12.93	6.01	13.50
	max	74	17	74	19	60
	min	-2	-2	1	-1	7
	n	176	39	77	13	47
F-test p =		0.36	0.25	0.97	0.74	0.66

Table 6.10 Initial radial angle difference

Mean, standard deviation, maximum and minimum value of the initial radial angle difference (R1) of all fracture types and of the four different types.

		T1234	T1	T2	T3	T4
CON	mean	6.10	0.42	8.27	3.33	10.12
	sd	8.27	2.69	7.58	4.76	10.75
	max	36	5	30	9	36
	min	-5	-5	-1	-3	-5
SAR	mean	6.97	1.55	8.59	0.25	9.29
	sd	5.84	2.98	5.30	3.30	5.42
	max	25	7	25	4	21
	min	-4	-2	3	-4	2
FUN	mean	4.77	-0.89	5.48	3.67	8.36
	sd	5.54	2.15	4.31	5.51	6.39
	max	19	4	12	10	19
	min	-3	-3	-3	0	0
total	mean	6.07	0.44	7.62	2.46	9.38
	sd	6.86	2.74	6.03	4.43	7.90
	max	36	7	30	10	36
	min	-5	-5	-3	-4	-5
	n	173	39	76	13	45
F-test p =		0.27	0.14	0.16	0.52	0.85

Table 6.11 Initial radial length difference

Mean, standard deviation, maximum and minimum value of the initial radial length difference (L1) of all fracture types and of the four different types.

		T1234	T1	T2	T3	T4
CON	mean	3.11	1.68	4.48	0.5	5.17
	sd	4.57	1.46	4.59	2.74	5.18
	max	17	4	17	6	17
	min	-3	-3	-2	-1	-2
SAR	mean	3.92	1.87	4.52	-0.25	5.82
	sd	3.80	2.02	3.14	0.96	4.41
	max	15	5	11	1	15
	min	-4	-1	-4	-1	-2
FUN	mean	2.98	0.83	3.67	1.67	5.09
	sd	3.59	0.92	2.80	2.08	4.37
	max	11	0	8	4	11
	min	-2	-2	-1	0	-2
total	mean	3.36	0.10	4.27	0.54	5.39
	sd	4.07	1.67	3.61	2.15	4.62
	max	17	5	17	6	17
	min	-4	-3	-4	-1	-2
	n	175	39	77	13	46
F-test p =		0.41	0.07	0.67	0.55	0.89

Table 6.12 Initial radial shift

Mean, standard deviation, maximum and minimum value of the initial radial shift (S1) of all fracture types and of the four different types.

		T1234	T1	T2	T3	T4
CON	mean	-1.62	-0.63	-1.96	-0.33	-2.65
	sd	2.14	1.34	1.48	1.63	3.14
	max	3	2	1	2	3
	min	-9	-3	-6	-3	-9
SAR	mean	-1.98	-0.64	-2.29	-0.25	-2.77
	sd	2.48	1.43	2.30	0.96	3.07
	max	5	1	2	1	5
	min	-8	-3	-8	-1	-6
FUN	mean	-1.84	-0.11	-1.48	-1.00	-4.18
	sd	2.70	0.60	2.91	1.00	2.18
	max	4	1	4	0	-1
	min	-11	-1	-11	-2	-7
total	mean	-1.80	-0.51	-1.95	-0.46	-3.07
	sd	2.41	1.23	2.25	1.27	2.92
	max	5	2	4	2	5
	min	-11	-3	-11	-3	-9
	n	172	39	75	13	45
F-test p =		0.69	0.55	0.47	0.74	0.35

table 6.13 Quality of reduction

Mean, standard deviation, maximum and minimum value of the volar angle, radial angle and radial length difference (V2, R2, L2) and radial shift (S2) after reduction, for fracture type 2 and 4.

		V2	R2	L2	S2
CON	mean	8.29	3.36	1.31	1.81
	sd	6.25	3.77	2.34	1.85
	max	25	11	9	6
	min	-8	-6	-4	-2
	n	49	48	48	48
SAR	mean	5.80	4.70	1.41	1.47
	sd	6.83	5.24	3.05	2.57
	max	19	23	11	6
	min	-11	-3	-6	-9
	n	49	49	49	49
FUN	mean	7.52	4.84	1.52	2.13
	sd	6.62	3.46	2.78	2.09
	max	22	13	8	6
	min	-3	-1	-4	-2
	n	31	31	31	31
total	mean	7.14	4.25	1.40	-1.77
	sd	6.61	4.32	2.72	2.20
	max	25	23	11	6
	min	-11	-6	-6	-9
	n	129	128	128	128
F-test p =		0.21	0.24	0.95	0.44

Table 6.14 Normal anatomy

Mean, standard deviation, maximum and minimum value and number of the volar angle (VA), radial angle (RA), radial length (RL) and radial width (RW) of the uninjured wrists.

	VA	RA	RL	RW
mean	11.15	26.21	11.48	16.97
sd	3.73	3.08	2.40	2.17
max	20	34	18	24
min	-1	18	6	11
n	179	179	179	179

Table 6.15 Normal motion in the wrist region

Mean, standard deviation, maximum and minimum value and number of dorsal flexion (DF), volar flexion (VF), radial deviation (RD), ulnar deviation (UD), pronation (PRO) and supination (SUP) of the uninjured side.

	DF	VF	RD	UD	PRO	SUP
mean	66.10	65.20	24.65	32.37	79.17	114.42
sd	8.43	8.95	5.07	5.83	16.65	13.21
max	95	88	40	50	120	140
min	45	35	10	18	40	40
n	184	184	184	184	184	184

CHAPTER 7
RESULTS

As a consequence of the formulated hypotheses (Chapter 4) outcome of the functional recovery, functional end results and complications in the three treatment groups are presented, as well as the anatomical end results and the relationship between the anatomical and functional end result.

7.1 Functional recovery

The speed of the functional recovery was assessed by the rapidity that the functional result score decreased (i.e. the functional result improved) between the subsequent check points during one year. In order to compare the same parameters at each check point (Table 5.9) the following parameters were excluded in the determination of the functional recovery:

- pain while wringing clothes
- loss of power
- subjective judgement of end results
- cosmetic appearance

During one year follow-up, the functional result score of the majority of the patients decreased rapidly initially, later on more gradually to reach low values (Figure 7.1). At all checkpoints the functional group obtained a lower mean score than the other two treatment groups (Figure 7.2). However, only in the beginning at week 4 was this difference statistically significant ($p=0.02$, Table 7.3), due to the difference between the functional and conventional group (contrast $p=0.01$). The contribution of the four involved parameter groups (Table 5.12) to the total score was calculated separately so as to find the most influential factors in the difference of the score at week 4. The "motion in the wrist region" and the "motor functions of the hand" turned out to be mainly responsible for the difference. The "complaints" and "signs and symptoms" did not contribute significantly to the difference (Table 7.4).

To investigate whether the difference in functional recovery between the treatment groups depended on the fracture type, the functional result score at week 4 was calculated for each fracture type separately. Sarmiento's fracture Type 1 and 3 turned out to be not significantly different with respect to the functional recovery as shown by a two way analysis of variance (Addendum 4). Regarding the functional recovery fracture Type 1 and 3 are therefore considered to be the same type of fracture (T 1/3). Fracture Type 1/3 obtained in the functional group a significantly lower mean functional result score at week 4 than in the conventional group. The mean score of fracture Type 2 was in the functional and in the Sarmiento group lower than in the conventional group. No significant difference between the groups was found in fracture Type 4 (Table 7.5).

7.2 Functional end result

The functional end result was determined by the functional result score one year after the trauma. In contrast with the functional recovery (Paragraph 7.1) all parameters of the functional result score were considered in the calculation of the functional end result. No statistically significant differences were found between the treatment groups (Table 7.6).

The functional end result was also calculated for the different fracture types separately. Analogous to the functional recovery fracture Type 1 and 3 were regarded to be the same type of fracture (T 1/3) with respect to the functional end result, as a two way analysis of variance did not reveal a significant difference between these types (Addendum 5). No significant difference between the treatment groups was found for the three distinct fracture types separately (Table 7.7).

In Chapter 6 imbalances between the treatment groups at baseline were presented (left-right distribution and presence of ulnar styloid fracture). As patients were not randomly allocated to the treatment groups it was imperative to adjust each important treatment comparison for baseline differences. To correct for these baseline differences (possible confounding variables) and at the same time to assess the prognostic value of the various recorded patient characteristics and early responses to the initial treatment, regression analysis was performed. In the regression analysis the functional end result was modelled as a linear function of possible prognostic and confounding variables and their interactions. The variables explored in this regression analysis were personal data (sex, age, profession, dominant hand), fracture type, fracture characteristics (ulnar styloid fracture, radio-ulnar joint involvement), initial displacement (initial volar angle difference (V1), radial angle difference (R1), radial length difference (L1), radial shift (S1)), quality of reduction (post-reduction volar angle difference (V2), radial angle difference (R2), radial length difference (L2), radial shift (S2)), method of treatment (CON, SAR, FUN) and anamnestic and objective parameters scored during the first two weeks (e.g. pain, swelling, opposition). After statistical exploration, some variables were left out because these appeared to be not important for the functional end result. The variables represented in the final regression analysis are listed in Table 7.8. The predictive value of the regression analysis is low as indicated by a low R-square value of 36%, which means that only 36% of the variation in the functional end result score could be explained by the prognostic variables. No clinically useful subgroups could be composed based on prognostic variables, that would obtain better functional end results with one method of treatment than with the other two methods. The method of treatment, even after correcting for the influence of other prognostic variables, definitely has no significant effect on the functional end result. The overall most important prognostic factors of the functional end result seem to be the initial volar angle difference (V1)($p=0.00$) and to a lesser extend the occurrence of an ulnar styloid fracture ($p=0.06$). When corrected for the influence of other prognostic variables the type of fracture appears not to be a significant prognostic variable. Treatment in the Sarmiento group seems unfavourable for patients with radio-ulnar joint involvement, but beneficial for patients with an ulnar styloid fracture. Due to the low R-square value, this conclusion probably has no clinical significance.

7.3 Complications

As indicated in Table 7.9, the number of cases in each group of complications separately was too low for statistical analysis. Therefore, all complications were added in each treatment group. No statistically significant difference was found in the incidence of all complications between the three treatment groups (Table 7.10). After correcting for the influence of possible confounding variables (like age, sex and radio-ulnar joint involvement) by means of regression analysis, still no significant difference was found.

- Complications due to cast or brace

Pressure sores or abrasions were found on nine occasions, a shifted brace was seen two times, plaster allergy was encountered once.

- Redislocation needing rereposition

Rereposition was done thirteen times at week 1 and four times at week 2. In nine cases the fracture type was 2, in eight cases the type was 4.

- Nerve injury

Median nerve compression (MNC) was diagnosed by EMG-study in 16 cases within 3 months after the injury. In 10 cases operative decompression resulted in relief of complaints. The other 6 cases were not operated on due to spontaneous improvement. The fracture type distribution was six times Type 4, six times Type 2, four times Type 1. None of these patients underwent a second reduction during the initial management, in one case rereposition at week 1 was performed. One year after the trauma, none of the 16 patients complained of MNC symptoms. In 8 out of the sixteen cases, EMG-signs of mild MNC were also found at the uninjured wrist, without causing complaints. Although the mean functional end result score in cases with MNC was higher than in all other cases, this difference was not statistically significant (Table 7.11).

- Tendon injury

Spontaneous rupture of the extensor pollicis longus tendon was seen two times (fracture Type 1 and 4). One patient underwent an extensor indicis proprius tendon transfer, the other refused operation. Five times stenosing tendovaginitis was seen within half a year after the trauma. Two cases were successfully treated with corticosteroid injection, in the other three cases this treatment failed and operative release was performed.

- Sudeck dystrophy

In seven cases Sudeck dystrophy (SD) stage 1 and in 7 cases stage 2 was found. Eight times the fracture type was 2, six times the type was 4. Two out of 14 cases underwent a second reposition during the initial management. The mean functional end result score in all cases of SD was significantly higher than in all other cases ($p=0.02$, Table 7.12), mainly due to the functional end result in cases with SD stage 2.

- Loss of radio-ulnar integrity (RUI) was diagnosed in 25 cases; three times in fracture Type 1, thirteen times in fracture Type 2 and nine times in fracture Type 4. Radio-ulnar joint involvement and ulnar styloid fracture were associated with loss of RUI in 15 (60%) and 14 (56%) cases. Three patients underwent a Darrach procedure during the second half of the first year, resulting in improvement of the complaints. The mean functional end result score of patients with loss of RUI was significantly higher than in all other cases ($p=0.00$, Table 7.13).

- Post-traumatic arthritis

One year after the trauma, post-traumatic arthritis (PA) was diagnosed in 31 cases, four times in fracture Type 1, ten times in fracture Type

2, three times in fracture Type 3 and fourteen times in fracture Type 4. Radio-ulnar joint involvement and ulnar styloid fracture were associated with PA in 18 (58%) and 13 (42%) cases. The mean final volar angle difference (V3), radial angle difference (R3), radial length difference (L3) and radial shift (S3) was respectively 9.30, 5.93, 3.93, 3.12, which is not significantly different from the mean values of all patients (Table 7.15). The mean functional end result score of cases with PA was significantly higher then of all other cases (p=0.04, Table 7.14).
- Loss of motion was found in twenty-one cases.
- Dupuytren's disease was seen five times, occurring within half a year after the trauma. No contractures were found during one year.

7.4 Anatomical end result
The anatomical end result was determined by the final volar angle difference, radial angle difference, radial length difference and radial shift, one year after the trauma (V3, R3, L3 and S3).

The anatomical end result in the functional group showed a significantly greater mean final radial angle difference and final radial length difference than the conventional group (contrasts p=0.01, p=0.00, Table 7.15), while the Sarmiento group showed a significantly higher mean radial angle difference than the conventional group (contrast p=0.04).
With respect to the anatomical end result, fracture Type 1 and 3 were regarded to be the same type of minimally displaced fractures (T 1/3); fracture Type 2 and 4 were regareded to be the same type of displaced fractures (T 2/4), as a two way analysis of variance did not reveal statistically significant differences between fracture Type 1 and 3 and between fracture Type 2 and 4 (Addendum 6). As shown in Table 7.16 and 7.17, the difference in anatomical end result between the groups is due to differences in displaced fractures (T 2/4). No significant difference was seen in minimally displaced fractures (T 1/3).

Analogous to the functional end result, a regression analysis was performed for each of the four anatomical end result parameters (V3, R3, L3 and S3). Again this was needed to correct for imbalances between the treatment groups at baseline and to assess the prognostic value of the various variables recorded at the beginning of the study.

The four regression analyses with dependent variables final volar angle difference, radial angle difference, radial length difference and radial shift, are listed in Table 7.18 to 7.21. The predictive value of the regression analyses however, is rather low as shown by low R-square values, indicating high percentages of unexplained variation. Due to this, no clinical useful subgroups could be composed on prognostic variables that would obtain better anatomical end results with one method of treatment than with the other two. The mean final radial angle difference and radial length difference in the functional group was still significantly higher after correcting for influences of other variables than in the conventional group (p=0.00, Table 7.19. p=0.00, Table 7.20). The most important prognostic variables of the anatomical end result were the initial displacement parameters. Age and the fracture characteristics radioulnar joint involvement and ulnar styloid fracture also seemed to have prognostic value. The fracture type had no prognostic value for the anatomical end result.

7.5 Relation between anatomical end result and functional end result.

The correlation between anatomical end result and functional end result was assessed by plotting the anatomical end results (V3, R3, L3 and S3) against the corresponding functional end result (FR). In a scatter diagram points clustering around a straight line and a correlation coefficient close to 1.0 would indicate a high linear correlation. In this study, no linear correlation was found as shown in Figure 7.22. In subgroups of younger patients (⩽50 years) some higher correlation coefficient between anatomical and functional end result were found than in the whole population (Table 7.23). In the calculation of aforementioned so called "crude correlations" no influence of other factors on the anatomical or functional end result was considered. As mentioned in Paragraph 3.13, a crude correlation coefficient is not a proper indication of a causal relationship. To investigate the causal relationship between anatomical and functional end result, the relations between "cause" and "effect" variables were formulated and analysed in a system of structural equations by means of "analysis of linear structural relationships". In this analysis, the "response" variables: "anatomical end result" (V3, R3, L3, S3) and "functional end result" (FR), were linked to the "explanatory" variables: "methods of treatment" (CON, SAR, FUN), "fracture types" (T1, T2, T3, T4), "fracture characteristics" (RU, US), "age", "initial displacement" (V1, R1, L1, S1), and were linked to the "intermediary" variables: "major complications" (COMPL: Sudeck dystrophy, median nerve compression, loss of radio-ulnar integrity, posttraumatic arthritis) and "anamnestic parameters" (ANAM: pain, numbness feeling, restricted daily life activities in the first two weeks), in a system of linear equations. The results are presented in two very condensed path-diagrams (Figure 7.24), one for patients above and one for patients below 50 years of age. These represent the essential information about the most interesting and relevant causal chains. The original path-diagrams, in which all above mentioned variables were linked, were too complicated for simple graphical expression. Only between the initial displacement, major complications, the anatomical end result and the functional end result relevant causal chains were found. All the other variables including the method of treatment, the fracture type and the age of the patient did not contribute to important or relevant causal chains. The arrows in the two presented path-diagrams indicate relations in the time and possible causal effects. Biological and clinical plausibility however, determines if these relations indeed can be regarded as causal. The corresponding values in the path-diagrams indicate "partial-correlations". (A partial correlation means a correlation between two variables that is corrected for the influence of other variables). Behind each partial-correlation the corresponding crude correlation is indicated in parentheses, frequently these two differed substantially. The partial correlations (PC's) between the anatomical end result and the functional end result were relatively low, compared to the other PC's (Figure 7.24). The PC between complications and functional end result was much higher in the younger group than in the older (0.56, 0.15). In the younger group, some high PC's were found between the initial displacement and complications (0.61), and between the initial displacement and the functional end result (0.70). In the older group one anatomical end result parameter (V3) showed relatively the highest PC towards the functional end result (0.31); in absolute sense however, this is still a very low partial correlation.

The most important factor influencing the functional end result in both the younger and older patients was the initial displacement. This factor had both a direct influence on the functional end result and an indirect influence via "complications" and "anatomical end result". In the younger group the intermediary influence of complications on the functional end result was relatively large. The initial displacement also seemed the most important causal factor determining the anatomical end result.

7.6 Conclusions

The functional recovery in the functional group tended to be quicker than in the other two groups. In the beginning, at week 4, this was statistically significant due to better motions in the wrist region and better motor functions of the hand. The early functional recovery was significantly faster in the functional group for fracture Type 1, 2 and 3 and in the Sarmiento group for fracture Type 2. In fracture Type 4, no difference in early functional recovery was found.

The functional end result was not significantly different in the three treatment groups. Prognostic factors of the functional end result were the initial displacement and occurrence of ulnar styloid fracture. The most important causal factors influencing the functional end result were the initial displacement and occurrence of complications. The method of treatment, the fracture type and the age of the patient were not important.

The incidence of complications was also not significantly different in the three treatment groups. Sudeck dystrophy, loss of radio-ulnar integrity and post-traumatic arthritis, were significantly associated with poor functional end results, while there was a trend in median nerve compression. Second reduction, rereduction, type of fracture, radio-ulnar joint involvement, and ulnar styloid fracture seemed to have no important relation with median nerve compression, Sudeck dystrophy or loss of radio-ulnar integrity. The fracture characteristics radio-ulnar joint involvement and ulnar styloid fracture were not highly associated with loss of radio-ulnar joint integrity or post-traumatic arthritis. The anatomical end result seemed not an important prognostic factor for development of post-traumatic arthritis within one year after the trauma. The occurrence of a Colles fracture might have altered subclinical median nerve compression into clinically manifest nerve compression.

The anatomical end result was in the functional group inferior compared to the conventional group, due to differences in displaced fractures. Minimally displaced fractures showed no significant difference between the treatment groups. Prognostic factors for the anatomical end result were the initial displacement, radio-ulnar joint involvement, ulnar styloid fracture, age and method of treatment. The most important causal factor influencing the anatomical end result was the initial displacement.

The causal relationship between anatomical and functional end result seemed very weak. (This is underlined by the significantly different anatomical end results in combination with equal functional end results in two methods of treatment.) The crude correlations were inreliable indications for the causal relationship.

In the analyses rather high percentages of unexplained variance were found. As the measurement errors were not great (Table 5.14), it is most likely that this was mainly due to extensive interpatient variability.

Sarmiento's fracture Type 1 and 3, as modified in this study, appeared to be the same type of fracture.

Figure 7.1 Functional recovery

Box plots of the functional result score (FR) for all cases at the subsequent checkpoints. The box plot indicates the upper and lower limits, the interquartile ranges and the median value.

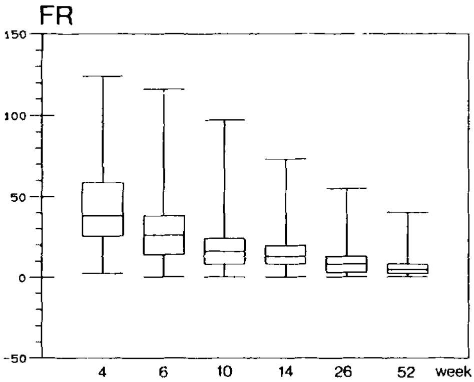


Figure 7.2 Functional recovery for each group

Mean value of the functional result score (FR) at the subsequent checkpoints for each treatment group.

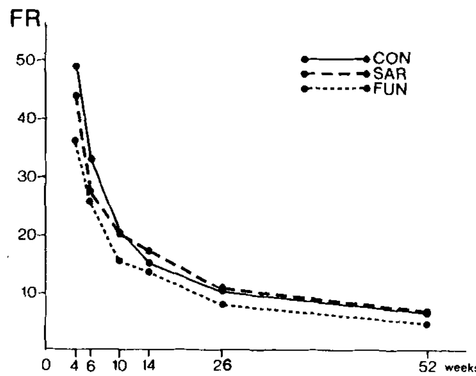


Table 7.3 Functional results per treatment group

Mean, standard deviation, maximum and minimum value and number of the functional result score (FR) at the subsequent checkpoints for each group for all fracture types.

	week	4	6	10	14	26	52
CON	mean	49.14	33.24	20.82	15.52	10.01	6.33
	sd	27.18	23.73	18.66	12.51	9.91	5.92
	max	120	111	97	62	55	40
	min	5	1	2	0	0	0
	n	73	72	74	73	74	73
SAR	mean	43.92	27.48	20.17	17.60	10.48	6.60
	sd	23.77	18.71	17.06	14.76	9.63	6.83
	max	124	116	89	73	53	35
	min	12	6	0	0	0	0
	n	65	60	64	63	61	58
FUN	mean	36.52	25.74	15.72	13.82	7.83	4.56
	sd	24.51	20.14	12.64	9.70	5.76	4.38
	max	106	109	78	46	26	22
	min	2	0	0	0	0	0
	n	47	46	46	45	42	43
F-test	p =	0.02*	0.11	0.28	0.78	0.53	0.20
t-test for contrasts							
C-S	p =	0.26					
C-F	p =	0.01*					
S-F	p =	0.08					

Table 7.4 Score of parameter groups

Mean and standard deviation of the score of the "complaints" (CO), "motion in the wrist region" (MW), "motor functions of the hand" (MH) and "signs and symptoms" (SS) at week 4.

	CO	MW	MH	SS
CON mean	6.23	14.69	25.97	3.34
sd	6.13	3.32	18.77	3.65
SAR mean	6.06	14.80	20.21	3.12
sd	6.16	4.01	16.09	3.22
FUN mean	5.43	11.96	16.91	2.19
sd	5.27	5.23	15.61	3.02
F-test p=	0.75	0.00*	0.01*	0.16
t-test for contrasts				
C-S p=		0.88	0.05	
C-F p=		0.01*	0.01*	
S-F p=		0.00*	0.28	

Table 7.5 Early functional result per fracture type

Mean and standard deviation of the functional result score at week 4 for fracture type 1 and 3 (T1/3), type 2 (T2) and type 4 (T4).

	T1/3	T2	T4
CON mean	33.08	56.72	60.11
sd	21.24	27.43	24.62
SAR mean	23.13	42.52	62.63
sd	8.86	18.97	24.82
FUN mean	16.15	43.14	47.36
sd	14.22	25.49	18.20
F-test p=	0.01*	0.05*	0.21
t-test for contrasts			
C-S p=	0.08	0.03	
C-F p=	0.00*	0.04	
S-F p=	0.06	0.88	

Table 7.6 Functional end result

Mean, standard deviation, maximum and minimum value and number of the functional end result score for each group.

	CON	SAR	FUN	total
mean	8.56	10.00	7.21	8.71
sd	8.30	10.56	6.78	8.81
max	53	49	33	53
min	0	0	0	0
n	73	58	43	174

F-test p= 0.62

Table 7.7 Functional end results for different fracture types

Mean and standard deviation of the functional end result score for fracture type 1 and 3 (T1/3), type 2 (T2) and type 4 (T4).

		T1/3	T2	T4
CON	mean	4.52	9.63	12.75
	sd	3.95	7.13	12.31
SAR	mean	3.00	9.36	16.41
	sd	2.31	8.74	13.42
FUN	mean	4.17	6.67	12.00
	sd	4.09	5.62	9.25
total	mean	4.04	8.77	14.02
	sd	3.62	7.42	12.04
F-test	p=	0.48	0.32	0.58

Table 7.8 Regression analysis functional end result

Regression analysis with dependent variable functional end result score (FR). The represented variables are methods of treatment (SAR, FUN), fracture type (T2, T3, T4), fracture characteristics radio ulnar joint involvement(RU) and ulnar styloid fracture (US), initial displacement ($\sqrt{V1}$) and combinations of variables. The variable FR is transformed to a logarithmic scale, the variable V1 is square root transformed and deducted with a constant factor for statistical analytic purposes.

log FR

variable	coeff.	st.error	t-test	p-value
Intercept	0.80			
SAR	0.03	0.10	0.31	0.76
FUN	-0.06	0.11	-0.52	0.61
T2	-0.01	0.12	-0.09	0.93
T3	-0.09	0.12	-0.76	0.45
T4	0.10	0.14	0.75	0.45
$\sqrt{V1}$	0.09	0.03	3.29	0.00 *
US	0.17	0.09	1.89	0.06
RU	-0.15	0.15	-1.03	0.31
SAR x US	-0.40	0.13	-3.15	0.00 *
FUN x US	-0.07	0.14	-0.50	0.62
SAR x RU	0.30	0.12	2.37	0.02 *
FUN x RU	-0.01	0.14	-0.07	0.95
RU x T2	-0.05	0.17	-0.28	0.78
RU x T3	0.71	0.38	1.86	0.06
RU x T4	0.10	0.19	0.54	0.59

multiple R-square: 0.36%

Table 7.9 Complications

Number and percentage of complications

	CON		SAR		FUN		total	
complications due to cast or brace	5	6%	3	4%	4	9%	12	6%
redislocation needing rereposition	5	6%	9	13%	3	6%	17	9%
median nerve compression	8	10%	5	7%	3	6%	16	8%
tendon injuries	6	7%	0	0%	1	2%	7	4%
Sudeck dystrophy	7	9%	5	7%	2	4%	14	7%
loss of radio-ulnar integrity	13	16%	8	12%	4	9%	25	13%
post-traumatic arthritis	13	16%	12	18%	6	13%	31	16%
loss of motion	6	7%	11	16%	4	9%	21	11%
Dupuytren's disease	3	4%	2	3%	0	0%	5	3%
total	66		55		27		148	

Table 7.10 Distribution of complications

Number and percentage of patients with 0, 1, 2, 3, 4 or 5 complications.

number of complications	CON		SAR		FUN		total	
0	36	44%	33	49%	28	60%	97	49%
1	32	39%	20	30%	14	30%	66	34%
2	8	10%	10	15%	2	4%	20	10%
3	6	7%	2	3%	3	6%	11	6%
4	0	0%	1	1%	0	0%	1	1%
5	0	0%	1	1%	0	0%	1	1%
total	82		67		47		196	

Kruskal-Wallistest p = 0.43

Table 7.11 Functional end result in median nerve compression

Mean, standard deviation and number of the functional end result score of three groups of patients with median nerve compression (MNC), compared to all other cases. From 15 out of the 16 patients, the score could be calculated.

	mean	sd	n	t-test p:
MNC all cases	10.08	8.64	15	
all other cases	8.61	8.84	159	0.58
MNC operated	13.67	11.18	8	
all other cases	8.53	8.71	166	0.31
MNC not operated	6.50	2.88	7	
all other cases	8.79	8.94	167	0.13

Table 7.12 Functional end result in Sudeck dystrophy

Mean, standard deviation and number of the functional end result score of three groups of patients with Sudeck dystrophy (SD), compared to all other cases. From 13 out of the 14 patients, the score could be calculated.

	mean	sd	n	t-test p:
SD stage 1+2	21.82	16.08	13	
all other cases	7.82	7.38	161	0.02*
SD stage 1	17.00	18.01	7	
all other cases	8.41	8.26	167	0.30
SD stage 2	27.60	12.82	6	
all other cases	8.18	8.07	168	0.03*

Table 7.13 Functional end result in loss of radio-ulnar integrity

Mean value, standard deviation and number of the functional end result score of patients with loss of radio-ulnar integrity (RUI) compared to all other cases.

	mean	sd	n	t-test p:
Loss of RUI	16.73	13.07	25	
all other cases	7.30	7.00	149	0.00*

Table 7.14 Functional end result in post-traumatic arthritis

Mean value, standard deviation and number of the functional end result score of patients with post-traumatic arthritis (PA) compared to all other cases.

	mean	sd	n	t-test p:
PA	12.79	11.29	31	
all other cases	7.93	8.07	143	0.04*

Table 7.15 Anatomical end results for all fracture types

Mean, standard deviation, maximum and minimum value and number of the final volar angle difference (V3), radial angle difference (R3), radial length difference (L3) and radial shift (S3) for all fracture types.

		V3	R3	L3	S3
CON	mean	11.21	3.90	2.31	2.18
	sd	9.10	4.98	3.28	2.56
	max	38	18	11	7
	min	-8	-6	-4	-9
	n	72	72	71	72
SAR	mean	9.25	5.85	3.10	2.92
	sd	11.88	5.64	4.68	2.93
	max	40	20	16	11
	min	-25	-4	-14	-8
	n	60	60	60	59
FUN	mean	12.00	6.67	4.63	3.05
	sd	12.41	6.09	4.03	2.41
	max	40	23	15	8
	min	-19	-1	-1	-1
	n	43	43	43	43
total	mean	10.73	5.19	3.16	2.64
	sd	10.96	5.65	4.07	2.67
	max	40	23	16	11
	min	-25	-7	-14	-9
	n	175	175	174	174
F-test	p =	0.41	0.02*	0.01*	0.15
t-test for contrasts					
C-S	p =		0.04*	0.27	
C-F	p =		0.01*	0.00*	
F-S	p =		0.49	0.08	

Table 7.16 Anatomical end results for displaced fractures

Mean and standard deviation of the final volar angle difference (V3), radial angle difference (R3), radial length difference (L3) and radial shift (S3) for displaced fractures (T2/4).

		V3	R3	L3	S3
CON	mean	13.65	5.02	3.22	2.67
	sd	9.64	4.97	2.94	2.41
SAR	mean	10.52	7.04	4.00	3.31
	sd	12.97	5.57	4.84	3.15
FUN	mean	13.59	8.09	5.56	3.56
	sd	13.29	6.12	4.15	2.54
total	mean	12.48	6.57	4.12	3.14
	sd	11.93	5.61	4.12	2.74
F-test	p =	0.38	0.04*	0.05*	0.32
t-test for contrasts					
C-S	p =		0.07	0.35	
C-F	p =		0.02*	0.01*	
F-S	p =		0.44	0.13	

Tabel 7.17 Anatomical end results for minimally displaced fractures

Mean and standard deviation of the final volar angle difference (V3), radial angle difference (R3), radial length difference (L3) and radial shift (S3) for minimally displaced fractures (T1/3).

		V3	R3	L3	S3
CON	mean	6.89	1.50	0.73	1.31
	sd	6.11	4.61	3.29	2.62
SAR	mean	5.07	1.93	0.14	1.64
	sd	5.79	3.93	2.38	1.50
FUN	mean	7.36	2.55	1.91	1.55
	sd	8.21	3.75	1.97	1.04
total	mean	6.49	1.84	0.82	1.45
	sd	6.46	4.20	2.84	2.06
F-test	p =	0.62	0.79	0.30	0.88

Table 7.18 Regression analysis final volar angle difference

Regression analysis with dependent variable final volar angle difference (V3). The represented variables are method of treatment (SAR, FUN), fracture type (T2, T3, T4), initial displacement ($\sqrt{R1}$,$\sqrt{V1}$,S1), fracture characteristics (RU), age and combinations of variables. The variables R1 and V1 are transformed to a square root scale and deducted with constant factors, the variables S1 and age are deducted with constant factors for statistical analytic purposes.

V3

variable	coeff.	st.error	t-test	p-value
Intercept	11.64			
SAR	-1.85	1.77	-1.05	0.30
FUN	0.37	1.97	0.19	0.85
T2	-1.34	3.26	-0.41	0.68
T3	-0.63	3.18	-0.20	0.84
T4	-1.24	3.39	-0.37	0.72
$\sqrt{R1}$	5.80	1.66	3.50	0.00 *
$\sqrt{V1}$	0.76	1.00	0.76	0.45
S1	-1.97	0.56	-3.51	0.00
RU	0.94	1.73	0.54	0.59
age	0.01	0.05	0.32	0.75
age x S1	-0.06	0.02	-3.18	0.00 *
RU x $\sqrt{R1}$	-6.97	2.30	-3.03	0.00 *
RU x $\sqrt{V1}$	2.41	1.19	2.02	0.05 *
RU x S1	2.10	0.78	2.68	0.01 *

multiple R-square: 0.30%

Table 7.19 Regression analysis final radial angle difference

Regression analysis with dependent variable final radial angle difference (R3). The represented variables are methods of treatment (SAR, FUN), fracture type (T2, T3, T4), initial displacement ($\sqrt{R1}$) and age. The variable R3 is transformed to a square root scale, the variable R1 is transformed to a square root scale and deducted with a constant factor, the variable age is deducted with a constant factor for statistical analytic purposes.

$\sqrt{R3}$

variable	coeff.	st.error	t-test	p-value
Intercept	2.92			
SAR	0.20	0.13	1.59	0.11
FUN	0.44	0.14	3.14	0.00 *
T2	0.21	0.16	1.29	0.20
T3	0.11	0.23	0.49	0.63
T4	0.10	0.18	0.56	0.57
$\sqrt{R1}$	0.47	0.07	6.91	0.00 *
age	0.01	0.00	3.26	0.00 *

multiple R-square: 0.40%

Table 7.20 Regression analysis final radial length difference

Regression analysis with dependent variable final radial length difference (L3). The represented variables are method of treatment (SAR, FUN), fracture type (T2, T3, T4), fracture characteristics (RU, US), initial displacement ($\sqrt{V1}$,$\sqrt{L1}$), age and combinations of variables. The variable L3 is transformed to a square root scale, the variables V1 and L1 are transformed to a square root scale and deducted with constant factors, the variable age is deducted with a constant factor for statistical analytic purposes.

$\sqrt{L3}$

variable	coeff.	st.error	t-test	p-value
Intercept	4.26			
SAR	-0.00	0.06	-0.03	0.98
FUN	0.19	0.07	2.93	0.00 *
T2	0.12	0.12	0.16	0.87
T3	0.01	0.11	0.08	0.94
T4	0.01	0.12	0.09	0.93
RU	-0.02	0.06	-0.41	0.68
US	-0.04	0.06	-0.63	0.53
$\sqrt{V1}$	0.03	0.03	0.76	0.45
$\sqrt{L1}$	0.47	0.07	6.64	0.00 *
age	0.01	0.00	3.06	0.00 *
RU x $\sqrt{V1}$	-0.07	0.03	-2.07	0.04 *
US x $\sqrt{L1}$	-0.16	0.08	1.92	0.05

multiple R-square: 0.49%

Table 7.21 Regression analysis final radial shift

Regression analysis with dependent variable final radial shift (S3). The represented variables are methods of treatment (SAR, FUN), fracture type (T2, T3, T4), initial displacement ($\sqrt{R1}$,$\sqrt{L1}$, S1), age and combinations of variables. The variables R1 and L1 are transformed to a logarithmic scale and deducted with constant factors, the variables S1 and age are deducted with constant factors for statistical analytic purposes.

S3

variable	coeff.	st.error	t-test	p-value
Intercept	1.80			
SAR	0.35	0.40	0.88	0.38
FUN	0.39	0.44	0.90	0.37
T2	0.82	0.52	1.59	0.11
T3	0.19	0.72	0.26	0.80
T4	0.57	0.58	0.98	0.33
$\sqrt{R1}$	-0.66	0.33	-2.03	0.04 *
$\sqrt{L1}$	0.85	0.44	1.94	0.05
S1	0.53	0.09	6.17	0.00 *
age	-0.00	0.01	-0.02	0.98
age x $\sqrt{L1}$	-0.04	0.02	-2.34	0.02 *
age x S1	0.02	0.00	3.48	0.00 *

multiple R-square: 0.39%

Figure 7.22 Correlation anatomical-functional end result

Scattered diagrams and correlation coefficients of the final volar angle difference (V3), radial angle difference (R3), radial length difference (L3) and radial shift (S3) against the functional end result score (FR) for all cases.

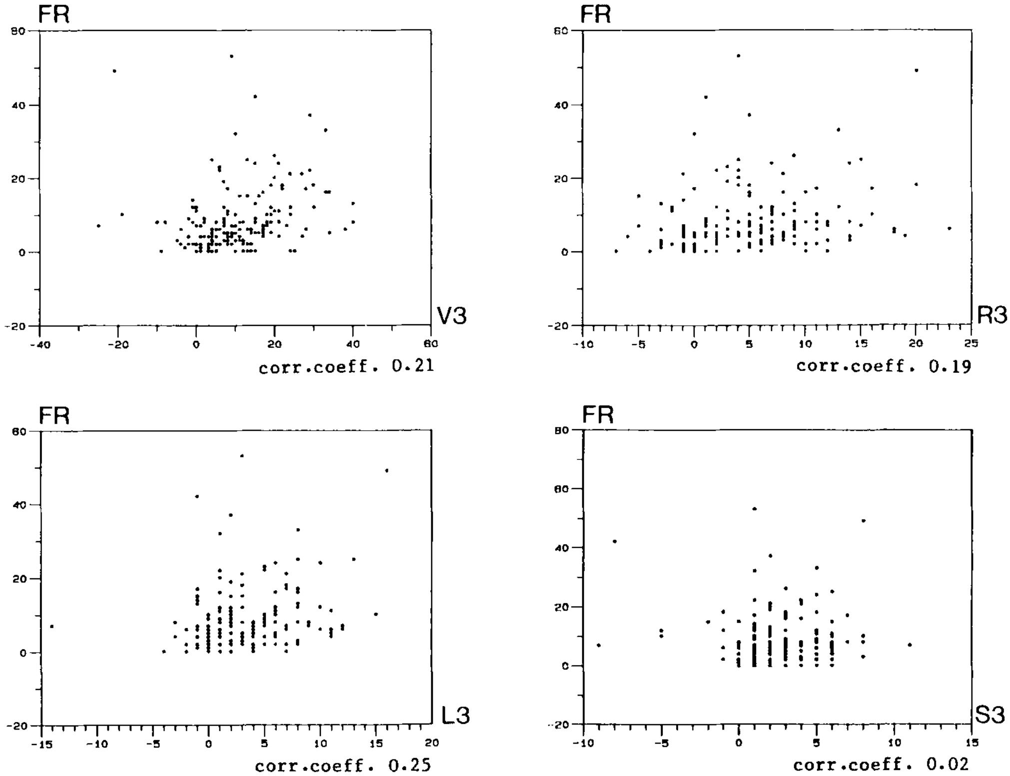


Table 7.23 Correlation coefficients

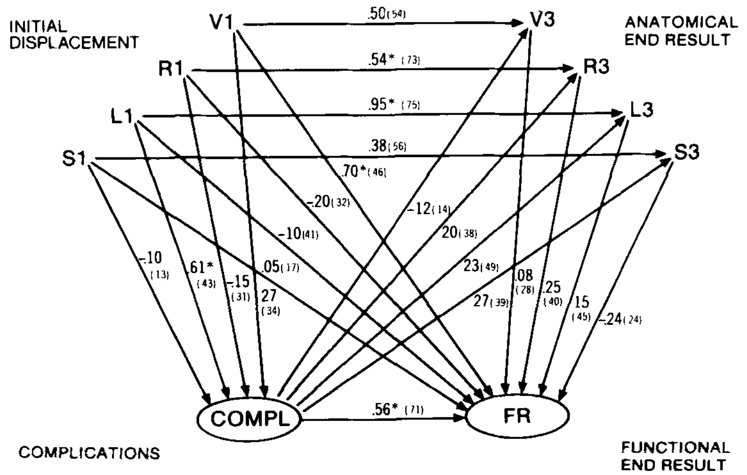
Correlation coefficients between the anatomical end results (V3, R3, L3, S3) and the functional end result scores for different groups of age or fracture type.

	n	V3	R3	L3	S3
all cases	166	0.21	0.19	0.25	0.02
T2/4	117	0.31	0.04	0.15	-0.10
T1/3	49	0.26	0.27	0.14	-0.01
age > 50	120	0.31	0.09	0.13	-0.10
age ≤ 50	46	0.07	0.40	0.54	0.22
age ≤ 50, T2/4	29	-0.16	0.29	0.51	0.19
age ≤ 50, T1/3	17	0.17	0.15	-0.11	-0.20
age ≤ 50, T2	19	0.26	0.06	0.29	0.06
age ≤ 50, T4	10	-0.26	0.45	0.60	0.25

Figure 7.24 Causal relationships

Analysis of linear structural relationships between initial displacement, major complications (COMPL), anatomical end result and functional end result score (FR) for patients of 50 years or younger and for patients over 50 years of age. Initial displacement is expressed in initial volar angle difference (V1), radial angle difference (R1), radial length difference (L1) and radial shift (S1). Major complications consist of Sudeck dystrophy, median nerve compression, loss of radio-ulnar joint integrity and post–traumatic arthritis. The anatomical end result is expressed in final volar angle difference (V3), radial angle difference (R3), radial length difference (L3) and radial shift (S3). Behind each partial-correlation coefficient, the corresponding crude-correlation coefficient is indicated in parenthesis. The percentage of unexplained variance of the various parameters is indicated at the right side.

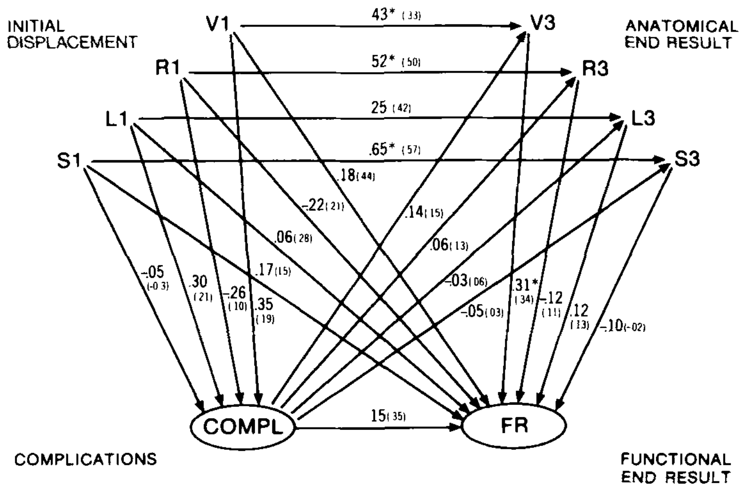
age ⩽ 50
n = 38



percentage of unexplained variance

FR:	36%
COMPL:	73%
V3:	57%
R3:	33%
L3:	34%
S3:	48%

age > 50
n = 107



FR:	64%
COMPL:	86%
V3:	72%
R3:	65%
L3:	70%
S3:	62%

CHAPTER 8

DISCUSSION AND CONCLUSIONS

8.1 Discussion

In the evaluation of treatment outcome, the wrist was considered as a "black box". This approach was based on the assumption that the patient will not complain of structural damage inside the wrist, but that the patient might be disabled by the results and consequences. Therefore no efforts were made to analyse structional damage inside the wrist. (except for radiographic examinations, necessary for analysis of relationships). The criteria for treatment outcome comparison used in this study were the speed of functional recovery, the functional end result and the incidence of complications. The anatomical end result was not used as a criterium.

The speed of functional recovery and functional end result were scored by a newly developed score system that considered the disability caused by the injury. Contrary to common score systems the functional recovery was assessed for the first time, all parameters were precisely defined, and the degree of disability resulting from loss of motion was rated according to generally accepted criteria. The uninjured wrist served as the individual standard, which proved to be important as a wide range of normal values was found in uninjured wrists. The results were not classified into groups with an excellent, good, fair or poor outcome as commonly encoutered in literature, as this would be arbitrarily, unnecessary and would result in for this study unwanted simplifications.
The new score system was designed to evaluate all possible important aspects of the functional result. This resulted in a wide score range. Because of large interpatient variability (especially in the beginning of the rehabilitation period) this wide range proved to be of value. The score system, however, is complicated and needs computer assistance. For that reason it seems unpractical and unsuitable for common use.

All complications during one year were considered to be related to the Colles fracture injury. The occurrence of median nerve compression or Dupuytren's disease in some cases might have been coincidental. This is however, hard to estimate as no exact figures exist about the incidence of these complications in the normal population (64,99).

The outcome of the study indicates that:
1. In displaced fractures functional treatment with a below—the—elbow functional brace and with Sarmiento's functional brace in supination are only superior to conventional plaster treatment in cases of extra-articular fractures by providing a faster functional recovery early in the rehabilitation phase (Hypotheses 1 and 2).
2. In minimally displaced fractures, functional treatment with a bandage is only superior to conventional plaster treatment giving a faster functional recovery early in the rehabilitation phase (Hypothesis 3).

3. The causal relationship between the anatomical end result and the functional end result in this study is very weak (Hypothesis 4).

These conclusions lead to some practical consequences for the treatment of Colles fractures:
- For displaced extra-articular fractures (Sarmiento Type 2) the limited gain obtained in speed of functional recovery with a below-the-elbow functional brace when compared to a conventional plaster has to be weighed in individual cases against the increased costs, necessary to apply the device.
- Sarmiento's functional brace in supination should not be used as it has no advantages when compared with a below-the-elbow functional brace but only disadvantages (more difficult to apply and less convenient for the patient).
- For displaced intra-articular fractures (Sarmiento Type 4) functional treatment should not be used.
- For minimally displaced fractures (Sarmiento Type 1 and 3) functional treatment with a bandage after one week immobilisation is the method of choice. Four weeks of immobilisation should be regarded as overtreatment for this fracture type.
- The inferior anatomical results obtained by the different types of functional treatment in this study are not shown to be detrimental to the functional results obtained with these methods of treatment.

Summarising the conclusions it appears that the benefits of functional treatment of Colles fractures are rather limited compared to four weeks of plaster treatment. However, treatment with a below-the-elbow plaster during only four weeks is also a rather functional approach because pronation and supination in the forearm are not fully restricted. If the functional treatment as applied in this study had been compared with a longer and more rigid immobilisation method of treatment the differences might have been greater.

The study extended over a follow up period of one year. Results at one year were regarded as representing the end results. With respect to the functional end result, this assumption seems acceptable as the functional score tended to stabilise during the second half of the year. The anatomical result is very unlikely to change after the follow up period. The incidence of the complications will not change after one year with the possible exception of post-traumatic arthritis which might influence the end results over a longer period. After one year this complication seemed unrelated to a poor anatomical end result. Future investigations however, are necessary to evaluate whether this finding remains the same in the long run.

Some remarks can be made when contrasting this study to the literature: Contrary to the majority of investigations this study is prospective and comparative with a standardised management of the injury and with precise definitions.
For the first time the speed of functional recovery, and the causal relationship between anatomical and functional end result are evaluated.
The superior functional and anatomical end results of functional bracing in supination over plaster cast treatment as claimed by Sarmiento et al (159,162) and Bünger et al (26) could not be confirmed.

This study supports the conclusion of Stewart et al (178) that no significant difference exists in the functional end result and the incidence of complications between plaster treatment and functional treatment.
The faster functional recovery, as claimed by Sarmiento, appeared only short lived and was restricted to some fracture types.
The impression that complications after Colles fractures are relatively common and a reason for unsatisfactory end results could be confirmed. Contrary to the opinion of the majority of the authors no important causal relationship between the anatomical and functional end result was found. This discrepancy might be due to the mixing up of correlation and causal relationship. The positive correlation between anatomical and functional result reported by some authors can be explained by the fact that both factors are causally related to a mutual factor: the initial displacement, possibly reflecting the severity of the injury. However, from such a possitive correlation a causal relationship cannot be concluded beforehand.

In search of the most beneficial type of functional treatment, different types were evaluated. The hardly existing causal relationship between the anatomical and functional end result means no contra-indication for further investigation on other types of functional treatment, restricting even less motion, with consequently higher chances of inferior anatomical results. However, the outcome of this study does not urge such further investigation as the benefit of functional treatment over conventional plaster treatment is rather limited.

The functional end result depends more on the initial displacement and on the occurrence of complications than on the method of treatment. The initial displacement cannot be influenced. Investigations on prevention and better treatment of major complications might therefore be the new frontier in the search for better functional end results after Colles fractures.

8.2 Conclusions

The application field of functional treatment in the management of Colles fractures is rather limited, when compared to conventional plaster treatment.

Sarmiento's functional bracing in supination has no place in the management of Colles fractures.

Functional bracing with a below-the-elbow brace has some slight advantage over conventional plaster treatment in displaced extra-articular Colles fractures.

Functional treatment with a bandage for three weeks after one week immobilisation is the method of choice in Colles fractures without initial dorsal angulation.

The causal relationship between the anatomical end result and the functional end result is weak in Colles fractures that are managed as described in this study.

The most important causal factors influencing the functional end result are not the method of fracture treatment, nor the anatomical end result, but the initial displacement of fracture fragments and the occurrence of complications.

For evaluation of functional and anatomical end results in Colles fractures, the non-injured wrist should serve as the individual standard because of large interpatient variability of normal values.

In Sarmiento's fracture classification, Type 1 and 3 should be changed to form one type of minimally displaced fractures (i.e. fractures without dorsal angulation).

Investigations on complications after Colles fractures might result in a better treatment outcome for this injury.

CHAPTER 9
SUMMARY

Chapter 1 Introduction
Functional treatment is a recently developed approach to a fracture injury with emphasis on early motion and function whereby fracture fragments are not immobilised but only stabilised. It is based on the assumption that especially soft tissue healing is important for proper rehabilitation. This aspect is given priority over bone consolidation in anatomical position. Retrospective studies indicate rewarding results of functional treatment in the management of Colles fractures. The aim of this thesis is to establish the application field of functional treatment of Colles fractures by comparing results from functional treatment with conventional plaster treatment in a prospective clinical study.

Chapter 2 The normal wrist and hand, review of literature
The motion in the wrist region, the function of the hand and the radiological anatomy are described as far as these appear relevant to this study.

Chapter 3 The Colles fracture, review of literature
Many aspects of the Colles fracture injury and its management are subject to controversial opinions. The results of various studies reporting different methods of treatment are hardly comparable. Very few prospective studies have been performed. The relation between the anatomical and functional result is crucial in the indication for most methods of treatment. This relationship however, remains unrevealed as the existence of a correlation is disputed and because the existence of a causal relationship between the anatomical and functional end result has never been investigated. The only reported type of functional treatment of Colles fractures is Sarmiento's functional bracing in supination, which is advocated regardless of the stability of the fracture. It appears that the current methods of treatment outcome evaluation show major drawbacks.

Chapter 4 Design of the study
Fracture stability and the kind of relationship between the anatomical and functional result seem important factors to determine the most beneficial type of functional treatment. Both factors are considered in the formulation of hypotheses that were tested in the clinical study. The criteria used for treatment outcome comparison are speed of functional recovery, functional end result and incidence of complications.

Chapter 5 Methods
The study was performed from 1981 till 1984. The patients were selected according to fixed criteria. Three treatment groups were formed. One group was treated with a conventional below-the-elbow plaster. The second group was treated with Sarmiento's above-the-elbow functional brace in supination that permited early volar flexion and ulnar deviation but restricted pronation of the forearm. In the third group displaced fract-

ures were treated with a below-the-elbow functional brace that permited early volar flexion, ulnar deviation and pronation and supination in the forearm; minimally-displaced fractures (volar angle > 0^{o}) were treated with a bandage that allowed motion in all directions. All fractures in the second and third group were initially immobilised with a plaster splint for one week to reduce pain and swelling. The total period of immobilisation or stabilisation in all groups was four weeks. All other aspects of the management of the injury were standardised.

A new score system for the functional recovery and functional end result is presented which reflects the patient's disability. The criteria for the diagnosis of complications are described. The anatomical result is based on four radiographic parameters. The fracture type is classified according to Sarmiento. The statistical methodology is outlined.

Chapter 6 Patient population
The total number of patients that participated in the study is 196; predominantly elderly women. Characteristics of the patient population like right-left distribution, fracture type distribution, initial displacement and quality of reduction are presented.

Chapter 7 Results
In the third, most functional treatment group, the speed of functional recovery is initially faster than in the other two groups for displaced extra-articular fractures treated with a below-the-elbow functional brace and for minimally-displaced fractures treated with a bandage. Also in the second group, treated with Sarmiento's brace in supination, an initially faster functional recovery is found compared to the conventional treated group, but only for displaced extra-articular fractures. In displaced intra-articular fractures, no difference in speed of functional recovery between the three treatment groups is found. The functional end result and the incidence of complications is not different in the three treatment groups. The anatomical end result of initially displaced fractures is in the third, most functional group, inferior to the first group treated with a plaster.
The causal relationship between the anatomical and functional end result is very weak. The initial displacement is a relatively important factor influencing both the functional and anatomical end result. Major complications appear another relatively important factor influencing the functional end result.

Chapter 8 Discussion and conclusions
The rather complicated newly developed score system is a keystone for the results and conclusions of this study. Functional treatment with a below-the-elbow functional brace appears beneficial in some selected cases of displaced extra-articular fractures. For minimally displaced fractures, a bandage for three weeks after one week immobilisation is the treatment of choice. Functional treatment should not be used for displaced intra-articular fractures. There is no place for functional treatment with Sarmiento's above-the-elbow functional brace. The overall importance of functional treatment of Colles fractures is rather limited when compared to conventional plaster treatment. This conclusion is in contrast to most reports in literature concerning this subject.

The positive correlation between the anatomical and functional end result, as reported by some authors, can be explained from the fact that both results depend on the same causal factor; the initial displacement. From this correlation a causal relationship between the anatomical and functional end result should not be concluded beforehand.

The hardly existing causal relationship between the anatomical and functional end result does not restrict further investigations of functional treatment types with more early motion and function and therefore with a higher chance on inferior anatomical results. The conclusions from this study however, do not indicate a need for further investigations in this direction.

Not the method of treatment, nor the anatomical end results, but the initial displacement, and complications are the most important factors in determining the functional end result. Of the latter two, the initial displacement cannot be influenced. Therefore, research on the complications after Colles fractures might be the new frontier in improving the treatment outcome of a Colles fracture injury.

CHAPTER 10

SAMENVATTING

Hoofdstuk 1, Inleiding
Funktionele behandeling is een recent ontwikkelde vorm van fraktuurbehandeling waarbij de nadruk wordt gelegd op vroegtijdige beweging en funktie. De fraktuur wordt hiertoe niet geïmobiliseerd doch alleen gestabiliseerd. Deze benadering berust op de veronderstelling dat de weke delen genezing van groter belang is voor een gunstig herstel dan strikte anatomische consolidatie. In retrospectieve studies worden veelbelovende resultaten vermeld van funktionele behandeling van Colles frakturen. Het doel van deze studie is om door middel van een prospectief klinisch onderzoek het toepassingsgebied van deze behandelingsvorm voor Colles frakturen te evalueren, door resultaten van functionele behandeling te vergelijken met die van conventionele fraktuurbehandeling met behulp van een gipsspalk.

Hoofdstuk 2, Literatuuroverzicht van de normale pols en hand
Van functionele en röntgenologische aspekten van de normale hand en pols wordt een overzicht gegeven, voor zover dit relevant is voor de opzet van de studie.

Hoofdstuk 3, Literatuuroverzicht van de Colles fraktuur
Over de meeste aspekten van het Colles fraktuurletsel blijken controversiële meningen te bestaan. De uitkomsten van velerlei studies over verschillende behandelingsmethoden zijn nauwelijks onderling te vergelijken. Het aantal gepubliceerde prospectieve studies is gering. Het veronderstelde verband tussen het anatomische en functionele eindresultaat is de basis voor de indicatiestelling van de meeste behandelingsvormen. Dit verband blijft echter onopgehelderd aangezien de meningen over een correlatie tussen beide verdeeld zijn en aangezien een oorzakelijke verband tussen beide nooit onderzocht blijkt te zijn. De funktionele behandeling volgens Sarmiento is de enige tot nu toe beschreven vorm van funktionele behandeling van Colles frakturen. Deze wordt ongeacht de stabiliteit bij iedere Colles fraktuur aangeraden.
Tenslotte blijken de gangbare evaluatiemethoden van behandelingsresultaten belangrijke tekortkomingen te vertonen.

Hoofdstuk 4, Onderzoeksopzet
De fraktuurstabiliteit en het verband tussen het anatomische en functionele eindresultaat lijken belangrijke factoren te zijn voor het bepalen van de meest optimale vorm van functionele behandeling. Deze beide factoren zijn betrokken bij het formuleren van de hypothesen die in de klinische studie getoetst zijn. Als criteria voor de vergelijking van resultaten dienen de snelheid van het funktionele herstel, het funktionele eindresultaat en de incidentie van complicaties.

Hoofdstuk 5, Methoden

De studie werd verricht van 1981 tot 1984. De patiëntenpopulatie kwam tot stand volgens vooropgestelde criteria. Er werden drie behandelingsgroepen samengesteld. Groep 1 werd geïmmobiliseerd met een conventionele onderarmsgipsspalk. Groep 2 werd behandeld met een tot boven de elleboog reikend funktionele koker volgens Sarmiento, waarbij volaire flexie en ulnaire deviatie toegestaan werden doch waarbij rotatie van de onderarm beperkt werd. In groep 3 werden verplaatste frakturen behandeld met een funktionele onderarms koker waarbij volaire flexie, ulnaire deviatie en onderarmsrotatie mogelijk waren. Minimaal verplaatste frakturen (volaire hoek groter dan 0^{o}) werden in deze groep behandeld met een zwachtel waardoor alle bewegingen mogelijk waren. Alle frakturen in de 2e en 3e groep werden in het begin gedurende één week met een gipsspalk geïmmobiliseerd. De totale immobilisatie of stabilisatie tijd in alle drie de behandelingsgroepen was vier weken. De overige onderdelen van de behandeling van het trauma werden gestandariseerd. Een nieuw score systeem voor het funktionele herstel en het funktionele eindresultaat werd ontwikkeld.

De criteria voor de diagnostiek van complicaties worden beschreven. De beoordeling van het anatomische resultaat geschiedt op grond van vier radiologische parameters. Voor de fraktuur klassificatie wordt Sarmiento's indeling gebruikt. Er wordt een beschrijving gegeven van de gebruikte statistische methodieken.

Hoofdstuk 6, De patiënten populatie

In totaal zijn 196 patiënten in het onderzoek betrokken. Het merendeel hiervan betreft vrouwen van middelbare en hogere leeftijd. Gegevens over de links-rechts verdeling, de frequentie der fraktuur typen, de oorspronkelijke fraktuurverplaatsing en de mate van succes van de fraktuur repositie worden vermeld.

Hoofdstuk 7, Resultaten

In groep 3, de meest funktionele behandelingsgroep, wordt in het begin een sneller funktioneel herstel gevonden dan in de andere twee groepen. Dit blijkt te berusten op een significant sneller funktioneel herstel bij verplaatste extra-articulaire frakturen en bij minimaal verplaatste frakturen. In groep 2, behandeld met de functionele bovenarmskoker in supinatie volgens Sarmiento, wordt bij verplaatste extra-articulaire frakturen in het begin een sneller functioneel herstel gevonden ten opzichte van de conventioneel behandelde groep. Bij verplaatste intra-articulaire frakturen wordt geen verschil in funktioneel herstel tussen de drie behandelingsgroepen gevonden. Zowel het funktionele eindresultaat als de incidentie van complicaties verschillen in de drie behandelingsgroepen niet significant. Het anatomische eindresultaat van oorspronkelijk verplaatste frakturen blijkt in de meest funktionele behandelingsgroep (groep 3) inferieur te zijn in vergelijking tot de conventioneel behandelde groep.

Er blijkt nauwelijks een oorzakelijk verband tussen het anatomische en funktionele eindresultaat te bestaan. (Bij frakturen die behandeld zijn zoals in deze studie, waarbij repositie en handhaven van een redelijke anatomische stand aandacht krijgen). De oorspronkelijke fraktuurverplaatsing en het optreden van complicaties blijken de belangrijkste bepalende faktoren van het funktionele eindresultaat te zijn. Ook blijkt de oorspronkelijke fraktuurverplaatsing de belangrijkste bepalende factor voor het anatomische eindresultaat te zijn.

Hoofdstuk 8, Discussie en conclusies

De resultaten en conclusies zijn voor een belangrijk deel gebaseerd op uitkomsten van het nieuw ontwikkelde vrij gecompliceerde evaluatiesysteem voor het funktionele herstel en het funktionele eindresultaat. Uit de uitkomsten van deze studie wordt geconcludeerd dat funktionele behandeling met een funktionele onderarmskoker in sommige gevallen van extra-articulaire Colles frakturen van nut kan zijn. Voor frakturen zonder oorspronkelijke dorsale angulatie is funktionele behandeling gedurende drie weken met een zwachtel, na één week immobilisatie, de behandeling van keuze. Funktionele behandeling van intra-articulaire frakturen heeft geen voordeel boven conventionele gipsspalk behandeling. Voor Sarmiento's funktionele behandeling met een tot boven de elleboog reikende funktionele koker lijkt geen plaats te bestaan. In het algemeen zijn de voordelen van funktionele behandeling van Colles frakturen boven conventionele gipsspalkbehandeling beperkt. Deze conclusie is in tegenspraak met de meeste publicaties over functionele behandeling van Colles frakturen.

De door sommige auteurs gerapporteerde correlatie tussen het anatomische en functionele eindresultaat kan verklaard worden uit het feit dat beide resultaten afhankelijk zijn van dezelfde initiële factor: de oorspronkelijke fraktuur verplaatsing. Uit een dergelijke correlatie mag evenwel op voorhand geen oorzakelijk verband geconcludeerd worden.

Het nauwelijks aanwezige oorzakelijke verband tussen het anatomische en functionele eindresultaat staat vervolg onderzoek naar functionele behandelingsvormen met nog meer vroegtijdige beweging en funktie en daarmee met grotere kans op inferieure anatomische resultaten, niet in de weg. Echter, de uitkomsten van deze studie geven aan dat er geen behoefte is aan verder onderzoek in deze richting.

Niet de behandelingsmethode, noch het anatomische eindresultaat, maar de oorspronkelijke fraktuurverplaatsing en het optreden van complicaties zijn de belangrijkste factoren die het funktionele eindresultaat bepalen. Van de twee laatst genoemde factoren is de oorspronkelijke fraktuurverplaatsing niet te beïnvloeden. Daarom lijkt onderzoek naar de oorzaak, preventie en behandeling van complicaties een nieuwe weg die ingeslagen moet worden naar verbetering van de behandelings resultaten van een Colles fraktuur letsel.

CHAPTER 11

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CHAPTER 12
ADDENDA

Addendum 1

<u>Information for the patient.</u> (all patients)

You have got a plaster because of a wrist fracture. The plaster is necessary for proper healing of the fracture. The first day your hand might show some swelling which is normal.
Important:
- Keep your arm in a sling during the day for the first three days.
- Keep your arm elevated on a cushion during the night for the first three days.

Return to the casualty department immediately,
- if the hand becomes numb, blue or white, or swells considerably.
- if pain increases much.

An appointment is made for plaster check up after one day. Subsequent appointments for check up will be made thereupon.
Stop using the sling after three days. Exercise finger and shoulder movements frequently during the day.
In case of complaints or questions you may contact the casualty department, telephone number 043-862059.

Addendum 2

<u>Information for the patient.</u> (brace treatment)

You have got a brace because of a wrist fracture. This brace enables you to perform exercises with the arm and hand. Exercises and motion are good for healing of the fracture and prevent stiffness of the hand. Keep your hand and wrist moving as often as possible during the day. Stretch the fingers and make a fist alternatively. Rotate your hand as far as possible, however prevent pain.

Or:

<u>Information for the patient.</u> (bandage treatment)

You have got a bandage after a fracture of the wrist. With this type of fracture, use of a plaster cast during one week is sufficient. After that, a bandage gives enough support. With this bandage motion in the wrist is possible again. As motion is important for quick recovery, exercise is very important. Try to move you wrist in all directions, however, prevent pain. Some slight discomfort is normal.
The fracture (crack) has not healed yet. Prevent lifting, carrying, pushing or pulling. Light daily work activities, dressing, eating or knitting are permitted.
The bandage is necessary during three weeks.

Addendum 3

<u>Information for the patient.</u> (all patients)

You have had a wrist fracture. The plaster, brace or bandage has been removed. For a fast recovery, exercises with the wrist and hand are very important. The best is to exercise in lukewarm water. Rotate the wrist as when stirring, move it up and down, to the right and to the left. Extend the fingers and make a fist alternately, squeeze out a sponge under water. Try to increase the excursions every day.
Exercise at least six times a day during a quarter of an hour.
Wringing, heavy lifting or sport should be postponed until a month after removal of the plaster, brace or bandage.

Addendum 4 Two way analysis of variance of the functional recovery

Two way analysis of variance to determine the effect of the method of treatment and the fracture type on the functional recovery. Mean and standard deviation of the square root of the functional result score at the subsequent checkpoints are presented for each treatment group and for each fracture type (T1, T2, T3, T4). The scores were square root transformed for the statistical analysis. Fracture Type 1 and 3 are not significantly different with respect to the functional result scores (T1-T3 p>0.05).

week	4	6	10	14	26	52
CON T1 mean	5.55	4.42	3.21	3.14	2.23	1.62
sd	1.95	2.02	1.19	1.03	1.30	1.00
T2 mean	7.34	5.92	4.86	3.74	3.22	2.46
sd	1.80	1.88	2.02	1.64	1.42	1.01
T3 mean	5.39	3.41	3.12	2.71	1.93	1.66
sd	1.21	1.17	1.21	0.83	0.97	0.96
T4 mean	7.60	6.13	4.47	3.76	2.96	2.66
sd	1.58	1.76	1.38	1.50	1.58	1.28
SAR T1 mean	4.37	3.38	2.17	2.37	1.74	1.42
sd	0.64	0.72	1.20	0.76	0.59	0.68
T2 mean	6.39	5.03	4.29	3.34	2.88	2.12
sd	1.34	1.19	1.51	1.59	1.23	1.17
T3 mean	5.73	4.21	3.18	2.77	1.78	1.56
sd	0.74	1.54	1.37	1.08	1.19	1.19
T4 mean	7.77	6.03	5.02	4.41	3.58	2.89
sd	1.54	1.72	1.96	1.71	1.68	1.42
FUN T1 mean	3.73	2.89	2.25	2.27	2.30	1.68
sd	1.86	1.47	1.36	0.92	0.88	0.52
T2 mean	6.41	5.28	4.16	3.35	2.50	1.75
sd	1.87	2.07	1.59	1.55	1.11	1.07
T3 mean	3.48	2.04	1.83	1.83	1.40	1.28
sd	1.37	1.77	1.58	0.71	1.06	1.43
T4 mean	6.78	5.45	4.42	4.08	3.17	2.38
sd	1.26	0.96	0.70	0.94	0.93	1.18
Two way analysis of variance F-test						
type-effect p =	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*
method-effect p =	0.00*	0.02*	0.11	0.59	0.71	0.43
type-meth.int.p =	0.28	0.41	0.47	0.48	0.38	0.72
t-test for contrasts						
T1-T2 p =	0.00*	0.00*	0.00*	0.01*	0.00*	0.01*
T1-T3 p =	0.53	0.53	0.74	0.48	0.35	0.83
T1-T4 p =	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*
T2-T3 p =	0.00*	0.00*	0.00*	0.02*	0.00*	0.06
T2-T4 p =	0.02*	0.13	0.48	0.02*	0.12	0.01*
T3-T4 p =	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*
T1/3-T2/4 p =	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*

Addendum 5 Two way analysis of variance of the functional end result

Two way analysis of variance to determine the effect of the method of treatment and the fracture type on the functional end result. Mean and standard deviation of the logaritm of the functional end result score is presented for each treatment group and for each fracture type (T1, T2, T3, T4). Fracture Type 1 and 3 are not significantly different with respect to the functional end result score (T1-T3 p>0.05).

	CON	SAR	FUN	Two way analysis of variance F-test		
T1 mean	0.59	0.52	0.65	type-effect	p=	0.00*
sd	0.39	0.25	0.26	method-effect	p=	0.62
T2 mean	0.93	0.85	0.76	type-meth.int.	p=	0.68
sd	0.33	0.41	0.36	t-test for contrasts		
T3 mean	0.67	0.53	0.45	T1-T2	p=	0.00*
sd	0.33	0.41	0.54	T1-T3	p=	0.75
T4 mean	1.00	1.12	1.02	T1-T4	p=	0.00*
sd	0.38	0.34	0.30	T2-T3	p=	0.01*
				T2-T4	p=	0.00*
				T3-T4	p=	0.00*
				T1/3-T2/4	p=	0.00*

Addendum 6 Two way analysis of variance of the anatomical end results

Two way analysis of variance to determine the effect of the method of treatment and the fracture type on the anatomical end result. Mean and standard deviation of the final volar angle difference (V3), square root of the final radial angle difference (R3) and final radial length difference (L3) and of the final radial shift (S3) are presented for each treatment group and for each fracture type (T1, T2, T3, T4). R3 and L3 were added with constant factors and square root tranformed for the statistical analysis. With respect to the anatomical end result, fracture Type 1 and 3 are not significantly different and fracture Type 2 and 4 are not significantly different (T1-T3 p>0.05, T2-T4 p>0.05).

			V3	$\sqrt{R3}$	$\sqrt{L3}$	S3
CON	T1	mean	6.56	2.50	3.94	1.17
		sd	5.24	0.91	0.42	3.03
	T2	mean	14.68	3.24	4.23	2.89
		sd	8.96	0.85	0.32	2.25
	T3	mean	7.63	2.99	3.96	1.63
		sd	8.12	0.81	0.35	1.41
	T4	mean	12.06	3.18	4.29	2.33
		sd	10.68	0.86	0.38	2.68
SAR	T1	mean	4.10	2.80	3.86	1.60
		sd	5.92	0.73	0.38	1.51
	T2	mean	9.82	3.46	4.22	3.07
		sd	13.47	0.87	0.74	2.83
	T3	mean	7.50	2.56	3.94	1.75
		sd	5.45	0.78	0.13	1.71
	T4	mean	11.61	3.62	4.45	3.67
		sd	12.47	0.68	0.53	3.65
FUN	T1	mean	6.63	2.71	4.03	1.60
		sd	6.91	0.45	0.17	1.06
	T2	mean	13.67	3.79	4.59	3.10
		sd	14.77	0.84	0.45	2.53
	T3	mean	9.33	3.30	4.31	1.33
		sd	12.74	0.84	0.29	1.16
	T4	mean	13.45	3.45	4.37	4.46
		sd	10.54	0.71	0.45	2.42

Two way analysis of variance F-test					
type-effect	p =	0.01*	0.00*	0.00*	0.00*
method-effect	p =	0.60	0.21	0.12	0.48
type-meth.int.	p =	0.98	0.65	0.56	0.80
t-test for contrasts					
T1-T2	p =	0.00*	0.00*	0.00*	0.00*
T1-T3	p =	0.51	0.30	0.43	0.90
T1-T4	p =	0.01*	0.00*	0.00*	0.00*
T2-T3	p =	0.17	0.03*	0.06	0.07
T2-T4	p =	0.86	0.60	0.78	0.35
T3-T4	p =	0.22	0.07	0.05	0.02*
T1/3-T2/4	p =	0.01*	0.00*	0.00*	0.00*

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