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# Scaphoid fractures

## *Studies on diagnosis and treatment*

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**Abstract**
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Scaphoid fracture is most common in young individuals of working age. Without adequate diagnosis and treatment, long-term results are poor. Operative treatment is being recommended increasingly often instead of a long time in cast, although there is no evidence-based support for its superiority.

The present thesis focuses on diagnostic problems and therapeutic consequences of acute scaphoid fractures and of scaphoid reconstruction when other treatments have failed.

Simultaneous plain radiographs and computed tomography were done in 97 injured wrists. Structural assessments of plain radiography images were highly predictive with respect to the risk of having a displaced or comminute fracture as diagnosed on computed tomography. Any finding of a gap or step-off > 0.5 mm, the presence of an intermediate fragment or a dorsal lunate tilt of ≥ 15° identified 81 % of fractures that were displaced or comminuted when investigated with computed tomography.

Eighty-three patients were randomly allocated to and received either nonoperative treatment in cast or operative treatment with the aim of assessing long-term outcome of the two treatment options. Fifty-two of the patients were occupationally active. From an occupational perspective with an early return to work, surgical treatment was superior in individuals with manual employment, and from a health economic perspective conservative treatment was superior in non-manual workers.

Patients treated for scaphoid fractures generally do well up to 13 years after the injury based on limb-specific outcome scores. No benefits were identified with operative treatment compared to non-operative treatment in cast. On the contrary, there was an increased risk for osteoarthritis in the scaphotrapezial joint in those who were operated.

The patient-rated long-term results of silicone implant arthroplasty were good, with pain relief and reasonable hand function in many patients up to 20 years after surgery.

*Keywords:* Scaphoid Bone, Wrist Joint, Wrist Injuries, Fracture Healing, Cost of Illness, Health Care Costs, Outcome Assessment (Health Care), Arthroplasty, Radiography, Health status

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To Karin and our children Ida, Anna, Johan and Jacob

# List of Publications

This thesis is based on the following papers, which are referred to in the text by their Roman numerals:

I Vinnars B, Petrén-Mallmin M, af Ekenstam F, Gerdin, B. Are plain radiographs adequate in assessing acute scaphoid fractures? A clinical study comparing plain radiography and computed tomography. Manuscript

II Vinnars B, af Ekenstam F, Gerdin B. Comparison of direct and indirect costs of internal fixation and cast treatment in acute scaphoid fractures: a randomized trial involving 52 patients. Acta Orthopaedica 2007; 78: 672–679
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III Vinnars B, Pietreanu M, Bodestedt Å, af Ekenstam F, Gerdin B. Nonoperative vs. Operative Treatment of Acute Scaphoid Fracture: a randomized clinical trial with ten year median follow-up. J Bone Joint Surg Am 2008 In press
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IV Vinnars B, Adamsson L, af Ekenstam F, Wadin K, Gerdin B. Patient-rating of long term results of silicone implant arthroplasty of the scaphoid. Scand J Plast Reconstr Surg Hand Surg 2002; 36: 39–45
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The studies are presented in logical rather than in chronological order.

Cover by the author

# Contents

# Abbreviations

| | |
|---|---|
| CT | Computerized tomography |
| DASH | Disability of the Arm Shoulder and Hand |
| LR | Likelihood Ratio |
| LR+ | Likelihood Ratio of a positive test result |
| LR- | Likelihood Ratio of a negative test result |
| MRI | Magnetic Resonance Imaging |
| PRWE | Patient Rated Wrist Evaluation |
| PEM | The Patient Evaluation Measure |
| ROM | Range of Motion |
| SD | Standard Deviation |

# Introduction

The word scaphoid comes from the Greek *skaphe*, which means something dug out or hollowed out and therefore with a shape that is similar to a small boat or skiff. The suffix *-oid* denotes something shaped like or resembling. The wrist bone bearing the name scaphoid can thus be envisioned as boat-shaped, although this is a great simplification. In previous nomenclature it was called the navicular. *Navis* is Latin for boat and naviculus uses the diminutive –ulus to signify a small boat.

## The scaphoid bone

The bony structure of the carpal joint differs widely among different animals. Even within different hominids, i.e. the monkeys that are closest to man, there are large differences between different species. Comparative anatomical investigations from the late 19th century have suggested a systematic phylogenetic development of the tetrapod forelimb based on adaption to a broad surface for contact with the ground. During this development each new finger ray is associated with a more complex wrist anatomy (Figure 1) [46]. The scaphoid is the result of fusion of the origins of the phylogenetically old structures os centrale ulnare distale and os centrale radiale distale, denoted “r” and “c1”, respectively, in Figure 1 [68]. It has been suggested that formation of the scaphoid bone is a phylogenetically recent occurrence and is a structural expression of the need for stability at the base of the index finger [65], and is related to the phase of knuckle-walking during phylogenetic development [68].

The scaphoid articulates proximally to the radius, distally to the trapezium and the trapezoid, and ulnarly to the lunate, and the capitate (Figure 2). It has a complex three-dimensional form and is to a large extent covered with articular cartilage, and it has five articulating surfaces facing the neighbouring joints [14, 27]. Based on the distribution of fractures, the scaphoid has conventionally been divided into three regions, the distal pole, the waist and the proximal pole.

The proximal aspect of the scaphoid consists of a convex hyaline cartilage facet articulating with the radius (Figure 2). Part of this articulating area extends over to the dorsal aspect of the scaphoid. The mid-portion of the dorsal aspect consists of a dorsal sulcus and a dorsal ridge, which is an area

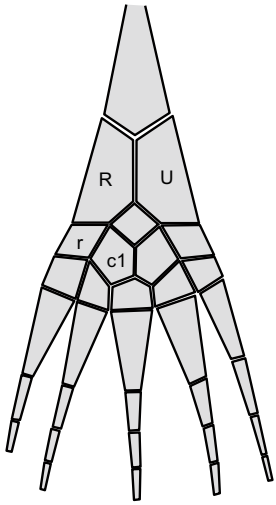


Figure 1. The systematic phylogenetic development of the tetrapod forelimb as described in [46].

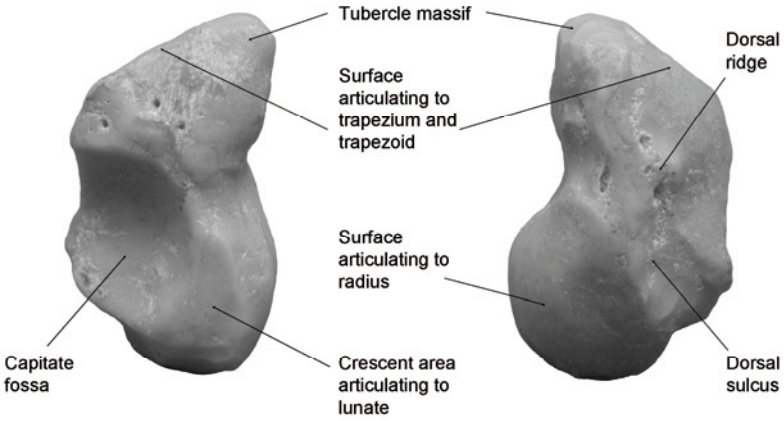


Figure 2. An ulnar (left), and a dorso-radial (right) view of the right scaphoid bone.

where ligaments attach and which delineates the border for the dorsal joint capsule. On the volar aspect of the scaphoid the proximal articular area continues up to the middle part of the bone, while the distal part consists of the tuberculum, which is an area for ligament attachment. The distal pole of the scaphoid consists mainly of hyaline cartilage and articulates with the trapezium and the trapezoid, and the tuberosity (the tubercle massif) is volar to this articulating facet. The medial or ulnar exterior of the scaphoid consists

of the proximal flat crescent articular surface for the lunate, and the distal large concave articulating area for the capitate.

The scaphoid is stabilized in position by means of a number of ligaments, the most important are volar. Along the ulnar edge and facing the lunate is the insertion zone for the scapholunate ligament with its three anatomic regions. The radioscaphocapitate ligament is volar, has an insertion on the scaphoid where the most radial fibres attach to the lateral surface of the waist of the scaphoid, and the central part inserts on the proximal surface of the distal pole [14, 15]. The scaphotrapezium ligament complex consists of four anatomical entities, a stout scaphotrapezial ligament on the radial and palmar aspects of the scaphotrapezial joint, weak palmar and dorsal capsules, and a scaphocapitate capsular ligament [36].

The vascular supply to the carpal bones is received by both extraosseous and intraosseous blood vessels. The nutrient arteries enter the bone through synovial and capsular attachments and form the extraosseous blood supply. After penetration of the cortex the vessels form the intraosseous supply within the medullary cavity.

The first study on the vascular supply of the scaphoid bone was published in 1910 by the German orthopaedic surgeon Georg Karl Felix Preiser [100]. Using an injection technique he observed that the major vascular supply originated from the radial artery and entered the bone on the dorsal surface. In 1938 Obletz and Halbstein [96] described the results of examination of vascular foramina in 297 dried scaphoid specimens. They found that 13% of the specimens had no arterial opening proximal to the midportion of the bone, 20 % had one foramen proximal to the waist, and the rest had two or more foramina in this location. In 1966 Taleisnik and Kelly [113] used an injection and dissection technique to investigate the scaphoid nutrient arteries. They reported that three vessels were observed to converge toward the scaphoid and that they originated from the radial artery.

A more recent study was performed by Gelberman and Menon [47] who investigated the external and internal vascularity of the scaphoid by a non-dissection technique (Figure 3). They reported that the major blood supply was via the radial artery and that two major blood vessels enter the scaphoid, one through its dorsal and one through its volar surface. Furthermore, they found that the proximal 70-80 % of the intraosseous vascularity, including the entire proximal pole, was derived from dorsal vessels entering the bone through the dorsal ridge, and the distal 20-30 % via volar branches entering the bone in the region of the tuberosity (Figure 4). All the vessels entered the bone in non articulating areas of ligament attachment.

Panagis et al [97] explicitly stated that the scaphoid, as well as the capitate, and, in some individuals, the lunate, had large areas of bone dependent on a single intraosseous vessel and that this was considered a risk factor for development of avascular necrosis following fracture (Figure 4). The dual

blood supply of the scaphoid supports the concept of an embryonic origin from two separate nuclei [114].

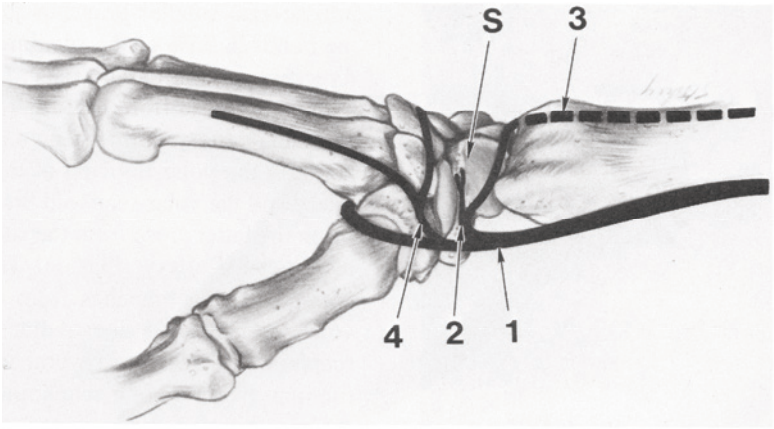


Figure 3. Schematic illustration of the dorsal blood supply of the scaphoid (S, scaphoid; 1, radial artery; 2, dorsal scaphoid branch; 3, dorsal branch of the anterior interosseous artery; 4, intercarpal artery). From reference [47]. With permission from Elsevier.

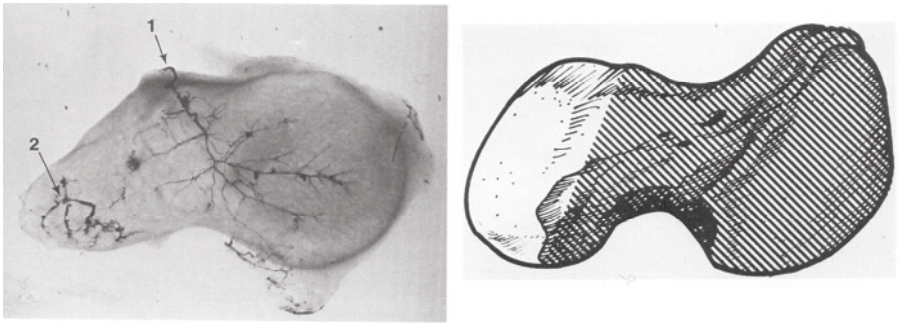


Figure 4. Left: Injection technique with cleared specimen revealing the internal vascularity of the scaphoid. (1, dorsal branch; 2, volar branch) From reference [47]. With permission from Elsevier. Right: Striped area of scaphoid that is supplied by the dorsal branch of the radial artery . The distal part supplied by the volar branch. From reference [47]. With permission from Elsevier.

## Fracture of the scaphoid bone

Scaphoid fracture is the most frequent carpal bone fracture, accounting for 60-70 % of all carpal bone injuries and 11% of all hand fractures [60]. Scaphoid fracture is most common in young men in the age group 15 to 29 years, who also have the highest incidence of non-union, take the longest time to unite, lose most time from work, and spend the longest time as out-

patients [74]. In a well defined population Hove reported that the annual incidence of scaphoid fractures was 4.3/10 000 persons and that 82 % of the fractures occurred in male subjects [60]. In a similar study from Denmark Falck Larsen et al. reported that the average annual incidence of scaphoid fractures was 8/100 000 females and 38/100 000 males [71]. Barton reported that for an average general district hospital serving about 250 000 people the estimated annual incidence would be 35 fractures a year [11]. An unvalidated hypothesis is that many people sustain fractures of the scaphoid which at the time are not recognized (by patient or by doctor). "Campbell's Operative Orthopaedics" estimates that 40% of scaphoid fractures are undiagnosed at the time of the injury [30].

## Mechanism

The mechanism is still incompletely understood [69]. Most patients with fractures have a history of a fall on an outstretched hand or a similar force resulting in hyperextension of the wrist [69]. Cadaver studies have suggested that hyperextension of the wrist beyond 95 degrees combined with a radial deviation places the scaphoid in a dangerous position. Here the proximal pole is locked within the scaphoid fossa while the rigid palmar capsule and the radioscaphocapitate ligament provide a pivot upon which the distal pole rotates [122] (Figure 5). Furthermore, similar studies have suggested that

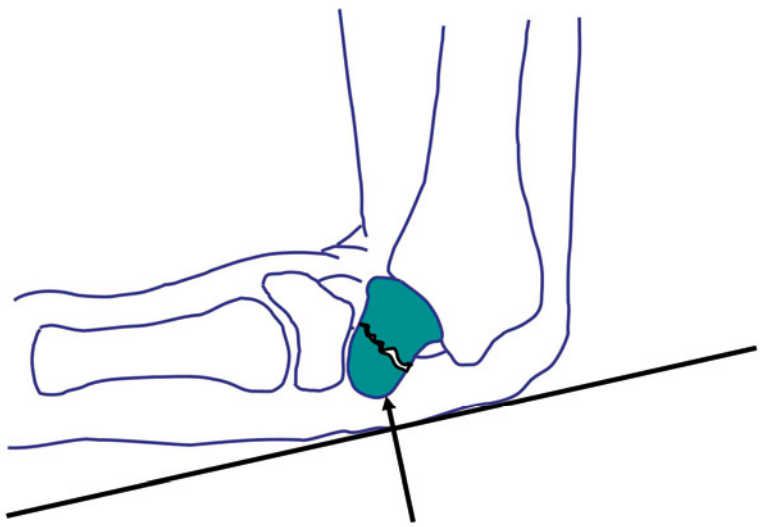

Figure 5. Principal mechanism for fracturing the scaphoid upon a fall on the outstretched hand.

scaphoid fractures are the result of a vector that emphasizes extension, and starts on the palmar surface and propagates dorsally [86]. However, some

patients with scaphoid fractures present with a different history than falling on an outstretched hand. Other mechanisms include a punch force [59] and a flexion force [79].

## Diagnosis

The injury is often related to sports, a traffic accident, work, or recreational activities. Although scaphoid fractures may seem common, most patients who appear at emergency care units with trauma to the wrist do not have scaphoid fractures. In a clinical study of patients with suspected fractures, only around 10% did in fact have a true fracture [64].

Most patients with a scaphoid fracture present with a swelling on the radial side of the wrist joint, particularly in the fossa Tabatière, "the anatomical snuff box", restricted and painful movement of the wrist joint, and a significant pressure tenderness over the snuffbox. However, a number of additional signs have been described [94, 119] (Table 1). The sensitivity and specificity of each of those signs is at best moderate, and none is reliable in diagnosing a scaphoid fracture.

The hallmark in diagnosing a scaphoid fracture is radiological. In a patient where clinical signs indicate that a scaphoid fracture is probable, plain radiography, utilizing a number of different views, is the primary investigation in most parts of the world. However, it has become clear that plain radiography of the scaphoid is associated with a certain degree of error. Even experienced observers will fail to see a fracture, and at times will falsely diagnose a fracture where there is none [35, 118]. To overcome this difficulty, scintigraphy, with higher sensitivity in detecting the presence of a fracture, has been recommended as a complement [50, 117]. This method may show that there is a fracture, but it is of little value in discerning the anatomical characteristics of the fracture.

The modern three dimensional visualization techniques of CT and MRI have been added to plain radiography in assessing scaphoid fractures. The additive value of such techniques is above all related to the fact that the two dimensional pictures of plain radiography are insufficient to reveal the minute details of the scaphoid anatomy due to the complex form of the scaphoid and the unavoidable superimposition of nearby carpal bones. Consequently, CT and MRI are presently recommended as the best option for assessing the detailed anatomy of the fractured scaphoid, and for detecting a scaphoid fracture [8]. CT has some inherent advantages in the examination of highly attenuated tissue such as bone, and the evolution of multi detector technology has improved the CT technique even further, and enhanced visualization of bone cortex and trabecular pattern [50]. It is therefore well suited for delineating the detailed anatomy of the scaphoid fracture and, in particular, occult cortical scaphoid fractures. However, it appears to be inferior to

Table 1. Various Clinical Signs in the Diagnosis of Scaphoid Fracture. Table from reference [94].

| Study | Clinical procedure/description | Sensitivity (%) | Specificity (%) |
|---|---|---|---|
| Powell et al [99] | Pronation of the affected wrist followed by ulnar deviation | 100 | 66 |
| Esberger [41] | Longitudinal pressure is placed down the thumb to compress the scaphoid (scaphoid compression test) | 71 | 22 |
| Verdan [123] | Pain on the radial wrist with resisted pronation | 68 | 73 |
| Zarnett et al [128] | Tenderness in the anatomic snuff box | 65 | 86 |
| Verdan [123] | Pain on the radial wrist with resisted supination | 63 | 82 |
| Barton [11] | Swelling in the anatomic snuff box | 48 | 60 |
| Barton [11] | Discoloration of the anatomic snuff box | 19 | 28 |

| Study | Additional clinical signs of scaphoid fracture |
|---|---|
| Cole et al [25] | Axial compression along the index and middle fingers |
| Soto-Hall [109] | Percussion on the tip of the abducted thumb or distal end of the second metacarpal |
| Soto-Hall [109] | Forced dorsiflexion of the hand |
| Hopkins [58] | Forced ulnar flexion of the wrist |
| Hopkins [58] | Percussion on the third metacarpal |
| Jacobsen et al [64] | Axial loading through the first metacarpal and the combination of full pronation and ulnar deviation of the hand |

MR-imaging in detecting solely trabecular injury [91]. Finally, high-spatial-resolution ultrasound has been suggested as a potential and reliable alternative early diagnostic tool for the evaluation of occult scaphoid fractures because of its high accuracy [45, 57].

These techniques are, however, only available for a small group of all those who present at emergency units. There is thus a need to learn more about how to extract a maximal amount of information from plain radiographs in order to optimize the utilization of CT or MRI for those where a true additive value is present.

## Fracture healing

The scaphoid bone is positioned intraarticularly and enclosed by hyaline cartilage, and a fracture is therefore repaired with endosteal healing [69]. This process requires a stable fracture allowing for bony ingrowth in the wound matrix [69]. Furthermore, bone viability is an obvious requirement.

A number of clinical features are considered important, as they affect the above-mentioned requirements. First, a close bone apposition will maximize the area of bone contact and increase the propensity for healing, while displacement will have the opposite effect. Carpal instability has been suggested as a factor for non-union because it will influence the stability of the fracture site [42]. Soft tissue interposition has been reported to be a cause of non-union or delayed union in trans-scaphoid perilunar dislocation injuries [124] and has also been suggested to occur in acute scaphoid fractures [55]. Furthermore, the intrinsic forces within the carpus itself act negatively on fracture healing.

The first carpal row is subjected to a torque force which includes the scaphoid. The distal part of the scaphoid is affected by a flexion force due to the scapho-trapezio-trapezoid articulation, and the proximal pole of the scaphoid tends to rotate into extension via the interosseous ligament to the lunate and the extension force of the triquetrum-hamate articulation. These diverse forces, taken together, tend to create an angulation of the fracture into flexion and reduce the contact area between the fragments [69].

Despite the above-mentioned inherent forces with a negative impact on optimal healing, the vast majority of non-displaced fractures will heal if treated promptly and properly [18, 80]. Displaced fractures, on the other hand, are associated with problems regarding healing. More than a 1 mm displacement of the fracture has been regarded as a risk factor for non-union [38]. Malalignment of the fragments into a flexion deformity will have a negative effect on healing and carpal kinematics and has been reported to lead to a poor outcome [7].

## Treatment options

### Conservative

Experience early in the 20th century revealed that if the fracture was not promptly diagnosed and protected by immobilization for an adequate amount of time, most fractures would not unite [11, 38, 67]. If not protected, osseous consolidation was considered the exception, and pseudoarthrosis between fragments the rule. For fractures with little displacement, expectant treatment consisting of massage and passive movement was advised. Considering these recommendations, it is not surprising that the outcome was poor.

The implications of adequate immobilization for an extended period of time soon became clear, and the previous pessimistic attitude changed. In 1954 Böhler et al. reported on a large series of scaphoid fractures treated with plaster immobilization with a 96% union rate [18]. Somewhat later, in 1960, London reported on 227 patients with fresh fractures treated conservatively with a union rate of 95% [80].

Since then the traditional treatment for non-displaced scaphoid fractures has been immobilization, usually involving 8-12 weeks in a cast. Early diagnosis and prompt treatment are mandatory to achieve success, and delay in diagnosing has been reported to increase the rate of non-union [70]. Different types of casts and whether to include the thumb or not have been the focus of several studies. There is general agreement that it is important for the wrist to be immobilized [11, 87, 88]. There is, however, considerable controversy concerning whether the fracture should be immobilized in a short arm or a long arm cast. The argument to include the elbow in the plaster cast was initially based on a study by Verdan, who found that supination caused movement at the fracture site in cadavers [123]. A clinical study involving 51 individuals has also revealed a shorter time to union with a long arm cast compared to a short arm cast [48]. However, this study assessed union based on trabeculae crossing the fracture line seen on plain radiography, a method which has been associated with poor interobserver agreement [34]. In contrast, in a study of 298 individuals Lindström found no difference between short arm and long arm casts in nondisplaced fractures [78]. Alho and Kankaanpaa conducted a prospective study of 100 individuals and found no difference in required immobilization time between long arm and short arm casts [5]. Experimental studies have also shown conflicting results. MacAdams et al. found no significant rotation at the minimally displaced scaphoid waist fracture during pronation and supination in a below elbow cast [87], and in an experimental arthroscopic evaluation study concluded that it appears safe to use a below elbow thumb spica cast in the treatment of minimally displaced scaphoid waist fractures [88]. On the other hand, Kaneshiro et al. found significant motion between the fragments with forearm rotation using stereophotogrammetric analysis in an experimental scaphoid waist fracture model [66].

Clinical studies including more than 460 individuals with scaphoid fractures treated with immobilization of the wrist leaving the thumb free have reported union rates of about 95% [18, 80]. In 1942 Böhler changed the method of immobilization and included the thumb in his series and this tradition appears to have spread [18]. Soto-Hall even recommended including the interphalangeal joint of the thumb in the cast [109]. In a large randomized study Clay et al. showed that inclusion of the thumb did not affect the union rate and concluded that "the simpler Colles´ cast would appear to be equally effective" [24]. Finally, in a recent systematic review of randomized or quasi-randomized trials Yin et al. concluded that there is insufficient evidence to determine which type of cast should be used in the nonoperative treatment of nondisplaced scaphoid fractures [125].

**Treatment – operative**

In 1954, McLaughlin described the use of a vitallium screw to stabilize fractures of the scaphoid. He had used the screw in 19 patients over nine years [89]. Somewhat later, Maudsley and Chen [85] reported the results of this approach in 56 patients, and emphasized the early mobilization and early return to work associated with this technique.

In 1969, McLaughlin and Parkes classified scaphoid fractures into three groups based on their operative findings [90], one unstable group and two types of stable fractures. A young English orthopaedic registrar, Timothy Herbert, was attracted by this perspective in the mid 1970s [12]. However, he found the screw fixation of scaphoid fractures difficult to do and tackled the problem by designing a jig and a screw that was smaller than the one used previously. In the process of doing so he came up with the original idea of a screw with two threaded sections of different pitches which would automatically provide compression. After moving to Australia he collaborated with an engineer, William Fisher, who made the first 100 Herbert screws in his garage. The early results were reported by Herbert and Fisher in 1984 [56]. The procedure enabled rigid fixation and early mobilization, usually without cast. In their first series of patients, all acute fractures were considered united at the 6-12-month follow-up. Based on their personal experience, the authors also suggested that the true incidence of non-union after nonoperative treatment was close to 50%. Additional studies reported good results using the Herbert bone screw, with high union rates [21, 43, 95, 108]. With the apparent advantages of rigid fixation, high union rate, short immobilization and early return to work, this method has, since its introduction, been an attractive alternative to the traditional cast treatment. On the other hand, this more complicated routine requires access to operative facilities, is more expensive, technically demanding and necessitates a high level of surgical skill.

The problems encountered are, first, the technical difficulties associated with this technique that are related to the complex three-dimensional anat-

omy of the scaphoid bone [2], and second, that the procedure requires insertion of the implant through the articulated distal surface of the scaphoid facing the scaphotrapezial joint, a process that theoretically involves a risk for development of secondary osteoarthritis [11].

## Consequences and sequelae

The true natural history of scaphoid fractures is not entirely known since a number of patients who sustain a fracture of the scaphoid do not appear for treatment. This may comprise up to 40 % of all scaphoid fractures [30]. Some of these will later present with non-union [11]. In order to determine the prevalence of non-union of scaphoid fractures, Sehat and Bannister reviewed 2857 radiographs of the wrist performed for any reason and found a prevalence of 0.14% in the general population [105]. Their interpretation was that the prevalence of not previously diagnosed sequelae of scaphoid fractures in the form of non-union is very low.

Furthermore, it is possible that a number of undiagnosed fractures do unite without treatment. This is not unlikely, at least for fractures that are stable [11]. A subgroup of patients will, however, experience continuation of symptoms. Dias et al. followed up patients with scaphoid fractures up to 2.6 years after the fracture and found that a number of patients with definite union continued to have symptoms of pain and tenderness [32].

The most important threat to the function of the wrist joint is non-union of the fracture. The risk for non-union is high in unstable fractures, in fractures with a gap between fragments, and in case of step off between fragments. A number of features characterize non-union: cyst formation, bone resorption, increased sclerosis, abnormal motion, displacement with dorsal angulation and shortening. Due to the altered carpal kinematics and instability, this will eventually result in joint space narrowing and progressive degenerative osteoarthritis.

The evolution of secondary arthritis of the wrist joint is the end result of several types of scaphoid and periscaphoid injuries [121]. Clinical symptoms are a more or less disabling pain, weakness, and limitation of movement. The incidence of radiocarpal osteoarthritis after non-union of the scaphoid increases with time. Ruby et al. [102] found that 31 out of 32 patients with scaphoid non-union had osteoarthritis after a period of five years or more. Lindström and Nyström reviewed 33 patients with non union of the scaphoid and re-examined them 10-17 years later. There was a 100 % incidence of progressive radiocarpal osteoarthritis [77].

Secondary arthritis is also a known sequel after proper treatment and primary healing. Lindström and Nyström reported that after seven years or more, 5% of healed scaphoid waist fractures developed post-traumatic arthritis in the radiocarpal joint [76]. They attributed this to alterations of carpal dynamics due to deformation and shortening of the scaphoid. A small step-

off between the fracture fragments, not detected on conventional radiographs, may also contribute to damage to the articular cartilage [13]. In a randomized study with a 12-year follow-up, Saedén et al. examined 42 patients and reported that 7 patients treated conservatively and 11 patients treated operatively with a Herbert screw had signs of radiocarpal osteoarthritis detected on CT examination [104].

## Treatment of secondary arthritis

Several treatment options have been recommended such as wrist arthrodesis [52], limited intercarpal fusion [121]), proximal row carpectomy [62], wrist denervation [20], and implant arthroplasty [111]. They all relieve pain but may have disabling effects, with additional reduction of movement and strength causing interference and loss of function at certain times.

Since its introduction in 1967, implant arthroplasty has quickly become a standard reconstructive procedure and has been used extensively. The implants were originally designed to act as articulating spacers and to maintain the relationship of the carpal bones after resection. The theoretical advantage of this procedure is that it relieves pain, retains movement of the wrist joint, and it has also been claimed to yield predictable results [111]. After several reports of a high incidence of microparticle-induced synovitis following carpal bone implants [22, 40, 92], the use of silicone implants in joint replacement arthroplasty has been drastically reduced. In contrast to these findings, several authors have reported good to excellent subjective results during the same period [17, 39]. Currently, the silicon implants have been replaced by implants made of titanium or pyrocarbon.

## Health economic aspects

Scaphoid fractures usually require a long time in cast in order to unite. Since this is an injury primarily affecting young, working individuals, the long immobilization time often has a serious impact on the ability to work, sometimes with consequences regarding employment, finances, and activities of daily life. Van der Molen and colleagues [120] studied time off work due to scaphoid fractures and found a mean value of 144 days for the 441 conservatively treated fractures studied. They also reported that only 2% resumed work with a plaster cast.

The total cost to society includes both treatment and work disability costs, with the latter responsible for up to 90% of the total cost in the treatment of scaphoid fractures [44].

Internal fixation of scaphoid fractures has previously been recommended primarily for displaced and unstable fractures, but there is presently an in-

creasing interest in recommending this treatment modality even in non-displaced fractures. Studies have suggested that internal fixation allows early mobilization of the wrist and earlier return to work [63, 85, 95, 104]. The development of minimally invasive techniques with limited or no immobilization minimizes surgical morbidity, and union rates approaching 100 % have been reported [3, 19, 63, 126].

The price for the hypothetical gain with a shorter time off work in those treated with an active surgical approach is a higher treatment cost. While conservative treatment in cast can easily be administered by the casualty doctor at the emergency clinic, internal fixation in an operating theatre requires more surgical skill and higher hospital costs.

Furthermore, the cost of a treatment failure is normally much higher than the cost for primary treatment. There are no investigations on the societal and hospital costs for the treatment failures of up to 10 % that may be the consequence of conservative treatment. Taken together, there is currently little consensus or scientific information on the overall economic pros and cons in choosing a treatment option for patients with scaphoid fractures.

## Patient ratings of wrist function.

Physical testing and radiological assessment of the scaphoid injuries are in themselves unable to capture the mental and social aspects of how the patient perceives his /her problems with the injured hand. Well-designed and properly applied questionnaires are better able to capture these aspects of a patient's health state. In choosing the best questionnaire for assessing the outcome after wrist injury, three characteristics need to be considered: reliability, validity, and responsiveness. Reliability is the ability to generate reproducible data. Construct validity refers to whether an instrument relates to other tests or measures as one would expect if it is really measuring what it is supposed to measure. Responsiveness is the ability to detect clinically meaningful change. The Michigan Hand Outcomes Questionnaire (MHQ) has 37 core questions covering six distinct scales [23]. The Patient Rated Wrist Evaluation (PRWE) was published in 1996 and contains 15 questions covering the three subscales pain, specific function, and usual function, reflecting impairment, disability and handicap [81]. The Disabilities of the Arm, Shoulder and Hand (DASH) Outcome Measure is a 30-item, self-report questionnaire designed to measure physical function and symptoms in patients with any or several musculoskeletal disorders of the upper limb [61]. The Patient Evaluation Measure (PEM) was constructed as a practical means of recording functional outcomes in hand surgery. It consists of a series of ten questions that address different aspects of symptoms pertaining to the hand and hand function [84].

In one study comparing the PEM, DASH and MHQ instruments, the internal consistency of all three questionnaires was very high, suggesting redundancy in the questions. All questionnaires were reproducible and valid for finger and wrist disorders, but less so for nerve disorders. The PEM was the easiest to understand and complete, and took the least time [33]. In a study of 60 patients with hand and wrist problems, both DASH and PRWE functioned well, although PWRE was considered slightly better as it captured relevant information with fewer questions [82].

# Background and Aims

The basis for the present investigation on scaphoid fractures was the key surgical question, Should scaphoid fractures be operated on or treated conservatively? From that simple approach, subsidiary questions arose quite naturally. Assuming that some fractures would benefit more than others from open surgical treatment, how should these be identified? What is the role of the most common diagnostic instrument, plain X-ray? What are the arguments for and against surgical treatment of a scaphoid fracture? Would a decision have economic consequences for health care or for the patient? What are the true long-term consequences of operative treatment vs. conservative treatment in cast? What are the real consequences for those individuals in whom treatment finally fails, and who need reconstruction in the form of a scaphoid prosthesis?

Based on these questions the specific aims of the study were:

- to search for objective measures in plain radiographic images that accurately indicate that acute scaphoid fractures are displaced, as diagnosed by CT investigations.
- to compare direct and indirect costs of operative versus nonoperative treatment in patients with acute scaphoid fractures, taking occupational status into account. Is surgical treatment a better choice based on the idea that economic benefits in the form of a reduction in time off work would well compensate for the cost of an operation?
- to evaluate the long-term outcome of the two different treatment modes, with respect to patient satisfaction, objective criteria in the form of wrist motion, wrist strength and radiological findings.
- to obtain a long-term evaluation based on patient ratings of wrist function after silicone arthroplasty using a wrist scoring instrument in a consecutive series of patients.

# Patients and Methods

For detailed information the reader is referred to the original papers I-IV.

## Study populations

The papers included in this thesis are based on two separate samples of patients who were treated at the Department of Hand Surgery (former Plastic and Hand Surgery), University Hospital, Uppsala, Sweden (Table 2).

Papers I-III are based on patients assessed for eligibility, and largely participating, in a randomized study on outcome of scaphoid fractures after operative versus nonoperative treatment in cast, with inclusion between 1992 and 1997. Paper IV is based on a retrospective study of patients who had been treated with total scaphoid excision during the time period 1974-1988, followed by silicon implant arthroplasty due to scaphoid bone pathology.

### Papers I, II and III

All patients who were referred to the Department of Hand Surgery, Uppsala University Hospital, Uppsala, Sweden, between 1992 and 1997, and who had a scaphoid fracture diagnosed by plain radiography, were assessed for eligibility in a randomized study comparing operative treatment vs. nonoperative treatment in cast

A total of 245 patients with injury to the scaphoid bone were assessed for eligibility (Figure 6), 85 were enrolled, and 83 received allocated treatment. Of the 160 patients who were excluded, 126 did not meet inclusion criteria, six refused to consent to the trial, and in 28 there were other reasons.

Paper I utilizes information from the 81 out of 85 randomized patients where simultaneous images from plain radiography and CT were obtained, together with the same information from the 15 patients assessed for eligibility due to a scaphoid fracture who were not finally included, but where both plain radiography and CT were performed. In total, 96 patients and 97 fractures were included in the study.

Paper II utilized information from the subgroup of occupationally active individuals participating in the trial, a total of 52 patients. Paper III presents the results of a 10-year follow-up of 75 out of the 83 patients who received allocated treatment.

Table 2. Papers and individuals included in the studies

| Paper | Type of study | Number of subjects | Data collection | Outcome measure | Data collection period |
|---|---|---|---|---|---|
| I | Consecutive patients | 96 | PR, CT | Radiological | 1992-1997 |
| II | Randomized clinical trial | 83 treated, 52 evaluated | Sick leave, hospital costs, work disability cost, total costs | Time absent from work, costs in € | 1992-97 |
| III | Randomized clinical trial | 83 treated, 75 evaluated | Questionnaire, DASH, PRWE, CE, PR, CT | Limb specific outcome scores, Clinical (ROM, strength), Radiological | 1992-97, Follow-up 2006 |
| IV | Retrospective descriptive study | 32 treated, 24/21 evaluated | Questionnaire, CE, PRWE | Limb specific outcome scores, | 1974-1988 Final follow-up 1999 |

CE= Clinical examination, DASH= Disability of the Arm Shoulder and Hand, CT= Computed tomography, PR= Plain radiographs, PRWE= Patient Rated Wrist Evaluation, ROM= Range of motion

### Paper IV

Thirty-two patients had the scaphoid totally excised followed by silicone implant arthroplasty at the Hand Surgery Unit, University Hospital, Uppsala, Sweden, between 1974 and 1988. All patients were referred for operation because of severe pain in combination with radiographic findings. The investigation of these patients consists of two parts: an intermediate follow-up in 1988/89 with clinical and radiological examinations, and a final follow-up in 1999 that included each patient's assessment of wrist function.

## Design of the randomized study (Papers I-III)

Inclusion criteria were an age of 17-65 years at time of injury, a history of trauma occurring less than 28 days previously, a radiologically mature skeleton, a single isolated non-displaced or minimally displaced scaphoid fracture (≤1mm) seen on plain radiograph, and an expected ability to comply with study instructions. Patients with pre-existing symptoms due to previous known skeletal wrist injury, fracture of the tuberosity or distal articular facet,

other co-existing wrist fractures or a trans-scaphoid perilunate dislocation were excluded.

Patients who agreed to participate were given written information about the risks and benefits of operative versus nonoperative treatment and verbal

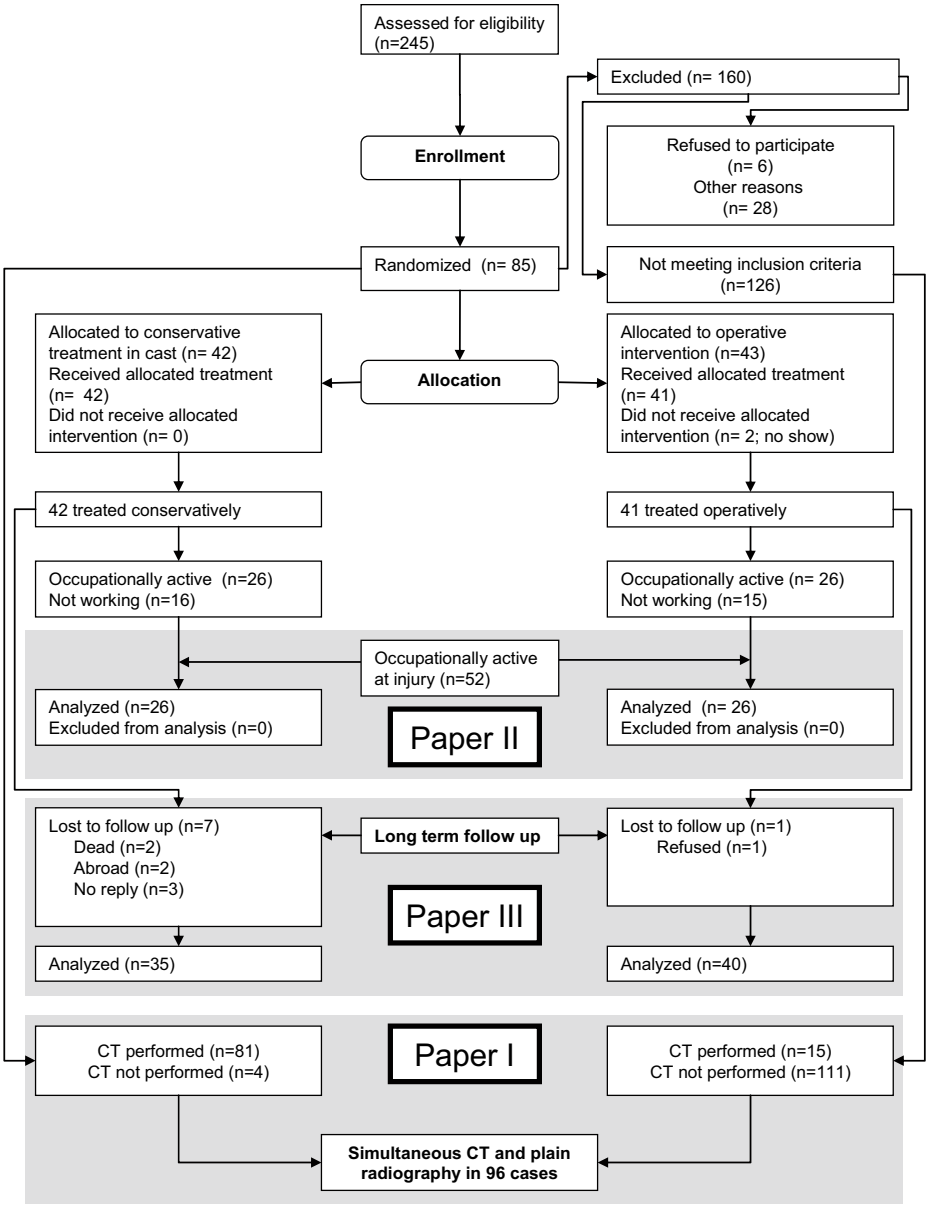


Figure 6. Diagram showing the flow of patients through each stage of the randomized trial according to the CONSORT statement (http://www.consort-statement.org).

consent was obtained. Classification of the fracture as a criterion for inclusion in the study was based solely on the plain radiographs, as in a standard clinical setting. After inclusion and randomization, all patients who entered the study were to be examined with CT of the injured wrist

Allocation was based on a table of randomized odd and even numbers generated by a computer and blocked in groups of eight. The allocation process was performed by a secretary and the results were concealed until interventions were assigned. Patients allocated to the nonoperative regime had treatment initiated by the doctor who was initially consulted. Patients who were assigned to the operative regime were scheduled for surgery as soon as practically possible, usually within a week

# Treatments

## Nonoperative treatment – acute scaphoid fracture (Papers II, III)

Forty-two patients were allocated to nonoperative treatment and obtained a below elbow scaphoid cast with the thumb in palmar abduction, the interphalangeal joint free, and the wrist in neutral or slight extension for an initial planned period of 6 weeks. The cast was then removed, radiology performed and, depending on the judgment of the surgeon, a new cast was applied for another period of 2-4 weeks. The surgeon was free to decide upon the intervals and number of follow-up visits and the need for radiographic control. The cast was removed when the fracture was considered united, and mobilization was encouraged. Union was based on clinical presentation, standard radiographs and occasionally CT. Hand therapy training was initiated when indicated. Mean time in cast was 10 weeks (range 3-20) in this group.

## Operative treatment – acute scaphoid fracture (Papers II and III)

Forty-one out of the 43 randomized patients received allocated operative treatment, which was performed under plexus blockade in 39 patients, general anaesthesia in one patient, and a combination of both in one patient. Patients were placed in a supine position with the arm on a radiolucent armboard. A tourniquet was routinely utilized. The scaphoid fracture was stabilized with a standard Herbert screw (Zimmer Inc., Warsaw, IN, USA) in 36 cases, and in two patients a cannulated Herbert-Whipple (Zimmer Inc.) screw was used. In two patients the bone screw was not positioned correctly and was therefore removed and the fracture treated nonoperatively, and one patient allocated to operative treatment did not receive the implant, as the fracture line was difficult to identify at surgery. Following the intention to treat principle these patients were analyzed in the operative group.

After skin closure, a well-padded short-arm noncircumferential dorsal plaster cast, leaving the thumb free, was applied for two weeks. In a few patients the immobilization time was extended due to findings at surgery such as incomplete ligament injury in two cases, and bone grafting in comminuted fractures in three cases. The cast was then changed to a thumb spica cast. The actual mean time in cast for the operative group was 3 weeks (range 2-16 weeks).

Two surgeons (BV and FaE) performed all operative procedures.

### Surgical technique – implant arthroplasty (Paper IV)

Out of the 32 operated patients, a volar approach was used in 29 patients and a dorsal approach as described by Swanson et al. in three [111]. After implantation of either the CSE type of Silastic implant (Conventional Silicone Elastomer, Dow Corning Wright, TN, USA) or the HP (High Performance) implant, the capsule was reinforced using the flexor carpi radialis tendon in one case, and a bone shell of the scaphoid was left in place in three patients. No intercarpal fusions were done. The wrist was immobilized postoperatively in a thumb spica for six weeks. Active motion of the fingers, elbow, and shoulder joint was started on the first postoperative day.

## Economic evaluation (Paper II)

The occupation of each patient was recorded using the Swedish socioeconomic classification [51] developed by Statistics Sweden (the central government authority for official Swedish statistics). In the present study the six groups of the original classification system were aggregated into two groups, “manual workers” and “non-manual employees and individuals who were self-employed”.

The medical records of all patients were reviewed and the number of outpatient visits and the details about all surgical procedures were recorded. In the surgical group the total time of surgery, anaesthetic time, and the number of days in hospital were recorded. Cost data for the different procedures during this time period were taken from the price list retrieved from the Hospital Accounting Department and the cost for each patient was then calculated. The hospital price list was constructed so as to fully cover costs for outpatient visits, in-hospital stays, and surgical procedures, and is based on a continuous internal cost analysis process.

The National Swedish Health Insurance System now covers 80% of an individual’s income (up to an upper income limit) during sick leave. This is currently paid by the employer (sick pay) for days 2–14, and thereafter by the Health Insurance System (sickness benefit). Both sick pay and sickness benefit are classified here as work disability costs. Payroll tax and value-

added tax are not included in the disability costs. For most patients, information on sick leave (i.e. time absent from work) and work disability costs covered by the Insurance Act were retrieved from the National Health Insurance Office. Where data retrieved in this way were insufficient, patients were contacted by telephone to obtain additional information. The medical costs and work disability costs for each patient were recalculated according to the consumer price index for 2003 (Statistics Sweden; www.scb.se). Costs are reported in € (euros).

# Radiological evaluation

## Plain radiography versus CT (Paper I)

Plain radiographs were performed on the ORBIX Isocentric arm unit (Siemens-Elema, Erlangen, Germany). Wrist radiographs were performed with the patient sitting and the hand resting on a support. The arm was abducted, the elbow was flexed, and the wrist was in neutral position. The postero-anterior view was obtained with the beam perpendicular to the wrist. Without moving the hand the tube arm was angled 90º medially from the frontal projection to obtain the lateral projection. Scaphoid radiographs were performed with the hand on a support, ulnar deviated. Four different images were obtained with the tube arm tilted 25º radially, 20º ulnarly, the ceiling arm turned 90º to the L-position and the tube arm tilted 10º distally, and finally the tube arm tilted 10º proximally [4].

CT scans of the injured wrist along the long axis of the scaphoid were performed using a Siemens Somatom Scanner HiQ or Plus (Erlangen, Germany) according to a standardized protocol. A wrist immobilization device was routinely utilized. The patient was lying prone on the x-ray table with the arm above the head, the elbow flexed and the wrist at a 45° angle to the gantry. The scanning plane was oriented along the thumb metacarpal, as this is an approximation of the longitudinal axes of the scaphoid. Scout images were obtained to ensure that the scanning plane corresponded with the longitudinal axis of the scaphoid. Images were acquired with continuous 1 or 2 mm slices, depending on the scanner.

All assessments were made by a senior staff radiology specialist in musculoskeletal radiology (M P-M). The plain radiographs were evaluated first, with access to patient identification, but without access to clinical information. After the interpretation was entered into the protocol, the CT from the same patient was assessed.

Measurements on plain radiographs included: the maximum visible gap in any of the images at the fracture site between the two fragments given in increments of 0.5 mm, the maximum step-off, i.e. the translation between the cortical surfaces of the two fragments in any of the images given in incre-

ments of 0.5 mm, the angular displacement between the two fragments based on an estimated angle between the proximal and distal fragment, the presence of comminution, defined as the presence of one or more intermediate fragments at the fracture site. Also included were assessment of other associated skeletal wrist injuries seen on any image, and visible fracture of both cortices of the scaphoid viewed in any image. Furthermore, the fracture was classified according to location, and using the classification systems of Russe [103], and Herbert and Fisher [56], the radiolunate and scapholunate angles [73] were measured, as well as the revised carpal height ratio [93].

Measurements on the sagittal CT images included the maximum gap between the two fragments, given in increments of 0.5 mm, the maximum step-off, i.e. translation between the two fragments given in increments of 0.5 mm at the palmar or dorsal cortical surface, the angular deformity, the presence of comminution, other associated skeletal carpal injuries, and the presence of a visible fracture of both cortices of the scaphoid at the fracture plane.

## The 10-year follow-up (Paper III)

Standardized images of both wrist joints were taken, as well as scaphoid images of the injured hand. Wrist images were performed with the wrist in neutral position (including neutral forearm rotation), with postero-anterior and lateral images. Four different scaphoid images were obtained with the palmar side of the wrist facing the x-ray table, one with the X-ray beam tilted 10° in the distal direction, one with it tilted 10° in the proximal direction, one with it tilted 20° in the ulnar direction and finally one with it tilted 25° in the radial direction [75]. CT scans of both wrists along the long axis of the scaphoid were performed on a Siemens Somatom Scanner (Erlangen, Germany) according to a standardized protocol. The protocol was similar to that described by Bain [10] except that the wrist was held in a neutral position. Images were acquired with continuous 0.75 mm slices. A wrist immobilization device was routinely utilized. Radiological assessments were made on an Impax Pacs DS 3600, Client workstation, release 4.5 (Agfa-Gevaert Group, Mortsel, Belgium). Osteoarthritis was graded as 1 (normal joint), 2 (narrowing of joint space), 3 (osteophytes), 4 (narrowing and osteophytes), and 5 (narrowing, osteophytes and subchondral sclerosis) [6]. The radiolunate angle was measured as described by Larsen et al [72, 73]. Carpal height and carpal height ratio were defined as described in references [49, 127]. The carpal height index was calculated according to [49, 110].

## Silicone arthroplasty (Paper IV)

At intermediate follow-up, standard radiographs of the affected wrist were obtained in both anteroposterior and lateral views in 23 of the 24 patients

evaluated. The forearm was held in a neutral position. The position of the implant was described as good, horizontally malpositioned or otherwise subluxed or dislocated. The position of the lunate, and degenerative changes or intraosseous cysts, or both, were specifically described.

# Clinical outcome assessment

## The 10-year follow-up (Paper III)

At a median of 10 years after the original injury (range 8-13) all patients were invited to undergo a re-examination. Of the original 83 patients, two had died, thus leaving 81 patients. Seventy-five of those (93%) attended the follow-up.

An unbiased surgeon not involved in the treatment phase of the study performed the clinical examination, which included inspection, evaluation of scar sensibility where applicable, tenderness at palpation, measurement of joint movement using a goniometer, and grip/pinch strength using the Jamar dynamometer (Sammons Preston Inc., Bolingbrook, IL, USA) and the Baseline Mechanical Pinch Gauge (Fabrication Enterprises Inc., White Plains, NY, USA).

Patients were also requested to answer a questionnaire containing general questions and questions on perceived hand problems, as well as two limb specific outcome instruments, the DASH (Disability of the Arm Shoulder and Hand)[9] and the PRWE (Patient Rated Wrist Evaluation) [83]. The DASH is a 30-item, self-report questionnaire designed to measure physical function and symptoms in people with any of several musculoskeletal disorders of the upper limb. The overall score can vary from 0 (best) to 100 (worst). The PRWE contains 15 items with three subscales, Pain, Specific Activities and Usual Activities. Each item is rated on a scale of 1 (best) to 10 (worst), thus giving a total of 150. Total scores were calculated to rate pain and function equally (14). The function score was therefore divided by 2 and added to the pain score. This gives a total subjective wrist score out of a possible 100, where higher scores indicate greater pain and disability.

## Silicone arthroplasty (Paper IV)

Nine months to 12.5 years after silicone arthroplasty patients were assessed in the outpatient clinic and their grip strength (Jamar dynamometer), pinch grip (Mannerfelt dynamometer), and range of movement of the wrist joint were recorded.

At this intermediate follow-up, four out of the 32 operated patients had had a wrist arthrodesis and one had had the implant removed. Of the remain-

ing 27 patients, 24 were subsequently examined. One patient had a bilateral arthroplasty, so 25 joints were examined.

At the final follow-up 10 to 24 years after surgery, the PRWE (Patient Rated Wrist Evaluation) questionnaire, see above [83], was sent to all patients who still had the implant. At this time 22 patients remained, and 21 of those could be assessed.

# Data analysis

## Assessment of plain radiographs and CT images (Paper I)

A logistic regression strategy was used with the presence of a displaced or comminuted fracture visible on CT as the dependent variable. Initial simple logistic regressions were followed by a final multiple logistic regression model with a backward stepwise elimination, and including covariates that were significant ($p<0.05$) in the initial models. Independent covariates were the available information from plain radiography in dichotomized form. The scapholunate angle was dichotomized at >60°, the radiolunate angle with a dorsal tilt ≥15°, and the revised carpal height at ≤1.50.

Intra-observer agreement in assessing CT – images was assessed for fracture angulation with measurements on two occasions more than one month apart. The intra-class correlation coefficient for measuring angulation was 0.98, and the 95% confidence interval for intra-observer agreement was ±0.4° when including all measurements; the figures were 0.95 and ±2.5°, respectively, when including only the 17 cases where there was angulation of fragments of ≥10° in either of the two measurements.

Sensitivity, specificity, discriminant ability (DA) and positive and negative likelihood ratios (LR+ and LR-, respectively) were calculated for each of the features of the plain radiographs. DA was calculated as (sensitivity + specificity)/2, and it describes the amount of overall information that the test supplies. An ideal test, which supplies all information and is never wrong, will have a DA of 1.0, whereas a completely ineffective test would have a DA of 0.5. In addition, the overall efficiency (OE) was expressed as the fraction that was correctly classified.

McNemar's test was used to compare paired proportions.

## Comparison of costs (Paper II)

A sample-size calculation was done using the t-test for 2 independent groups. The planned immobilization time in the operative group was 2 weeks and the expected time off work was 6 weeks. The immobilization time in the cast group based on clinical practice was 10 weeks on average, and the expected time off work was 12 weeks. A calculation indicated a need

for 26 patients in each group to provide a power of 91% to detect a difference of 6 weeks (alpha 0.05, 2-tailed, SD 45).

The results are presented as medians and 95% non-parametric confidence intervals. Differences between groups were assessed by the Mann-Whitney U test.

### Ten-year follow-up (Paper III)

An intention-to-treat principle was utilized in the analysis. Results are descriptively presented as means, medians and 95% Confidence Intervals. Nominal data were analysed with Fisher´s exact test and Chi-square test where applicable, and interval data with the T-test if the data were considered normally distributed. For non-parametric statistics the Mann-Whitney U test was utilised.

Long-term results of silicone implant arthroplasty (Paper IV)

Data are expressed as means (SD) or medians (range) as appropriate.

## Ethics

All studies were performed according to the principles of the Helsinki Declaration [1] and were approved by the Uppsala University Ethics Committee.

# Results

## Paper I

Out of the 97 fractures assessed in 96 patients, 22 fractures had a gap ≥ 1 mm, 17 had a step-off ≥ 1mm between the fragments, 28 had either gapping or a step-off, and 10 had both gapping and a step-off, all when assessed by plain radiography. Thirty-five fractures had intermediate fragments, 9 had other associated skeletal injuries and 8 had a radiolunate angle with a dorsal tilt ≥15°.

CT identified more patients with fracture gaps and step-off than plain radiography. Thus, 30 fractures had a gap ≥ 1 mm at the fracture site, and 22 had a similar step-off between the fragments. There were 39 fractures with intermediate fragments and 11 with other associated skeletal injuries. Finally, 17 fractures had an angular deformity ≥10°. In all, 55 fractures were diagnosed as displaced or comminute and 42 as not.

A simple logistic regression analysis was undertaken to identify which of the characteristics of the plain radiography images were best related to the presence of displacement or comminution as diagnosed on CT. The presence of an intermediate fragment was the best predictor of displacement or comminution with a Nagelkerke's $R^2$ of 0.31. The presence of a visible gap between fragments, as well as a step-off, was also strongly related to displacement or comminution. Finally, classification according to Herbert and Fisher, and the presence of bicortical injury, were related, although more weakly, to displacement or comminution. Those characteristics that were significant in simple regressions were subsequently included in a multiple logistic regression with backward exclusion. This revealed that the presence of an intermediate fragment on plain radiography was still the strongest independent predictor, followed by the presence of a step-off and gap at the fracture site. The final model explained 50 % of the variance of the dependent variable.

A combined assessment including one of four characteristics seen on plain radiography: step-off or gapping of more than 0.5 mm, one or more intermediate fragments, or a radiolunate angle with a dorsal tilt ≥15°, identified displacement with a sensitivity of 0.82, a specificity of 0.79, and an overall efficiency of 0.81. Only nine displaced or comminuted fractures were not correctly classified using this approach.

## Paper II

The median time of absence from work for the 52 patients did not differ significantly, 74 vs. 39 days, between those treated non-operatively in cast and those given operative treatment. However, those with manual work had a longer time off work than the non-manual employees/self employed (median time 84 days as opposed to 16 days; $p < 0.001$). In the manual worker group there was a significantly longer period of absence from work in those treated non-operatively in cast than in those undergoing surgery (median 100 days and 61 days, respectively; $p = 0.03$). In contrast, there was no difference regarding absence from work between those treated non-operatively and those treated operatively in the non-manual employees/self-employed group. Hospital costs were higher in the operated group than in the non-operative group ($p < 0.001$). There was no difference in hospital costs between those with manual work and those in the non-manual employees/self employed group.

Work disability costs were not statistically significantly higher in the non-operatively treated group than in those who underwent surgery. However, work disability costs were statistically significantly higher in the manual workers than in the non-manual employees/self employed group (median €2,847 as compared to €99; $p < 0.001$). There was no statistically significant difference in work disability costs between the two treatment regimens. With respect to socioeconomic classification, the total costs were higher in manual workers than in the non-manual employees/self-employed group (median €4,396 as opposed to €1,240; $p < 0.001$). In the non-manual employees/ self employed group, the total costs were lower in those treated non-operatively in cast than in the operated group (€770 and €2,253, respectively; $p < 0.05$). This can be explained by the fact that more than half (7 of 13) of the non-manual employees/self employed individuals were able to work with a cast and consequently had no work disability cost.

## Paper III

Ten years after being treated for an acute scaphoid fracture the patients in this study generally perceived having good upper limb and hand function, based on the results of the limb specific outcome instruments. There was a low mean score on both the DASH instrument (4 in the nonoperative treatment group and 3 in the operative treatment group) and the PRWE (6 in the nonoperative group and 6 in the operative group; ns), which indicates that most patients were free from symptoms in the wrist joint. Only 2 patients scored high, and in neither of them were the symptoms related to the previous scaphoid fracture.

The range of motion (ROM) of the wrist joint was numerically higher in the nonoperative group compared to the operative group, and this was significant regarding radial deviation. However, when compared to the non-injured side the difference was not significant. The same was true for grip strength and pinch strength, where the nonoperative group had numerically but not significantly higher values.

All 75 fractures were united at the 10-year follow-up. Malpositioning of the screw, defined as part of the screw protruding outside of the cortical boundaries of the scaphoid, was found in 14 individuals examined with CT, although most of the protrusions were minor and probably well within the articular cartilage. The most important observation was a significant increase in scapho-trapezial joint osteoarthritis assessed by CT and plain radiography in the operative group. However, those who were diagnosed with osteoarthritis by means of CT did not differ from the remaining 63 with respect to perceived upper limb and hand function as assessed by the DASH and PRWE instruments (data not shown).

## Paper IV

At the intermediate follow-up there was a minor reduction in grip strength in the affected hand compared to the non-injured hand, but no difference in pinch grip strength. The range of motion of the wrist joint of the affected hand was 74% and 81 %, respectively, in dorsal extension and in volar flexion compared to the non-injured hand.

Of the 24 wrists examined radiographically, only 10/24 implants were in the correct position, whereas in 14/24 the implant had rotated or become dislocated. The lunate was tilted dorsally in 19/24 wrists, suggestive of a carpal instability. Intraosseous cysts were found in 15/24 wrists, some quite large. The silicone implant arthroplasty failed to prevent progression of post-traumatic arthritis, since degenerative arthritis had developed between the capitate and lunate in 11/24 wrists.

At the final follow-up the patients' assessments of their wrist function varied widely. The mean PRWE rating of pain was 27 (SD 26) and for function it was 22 (SD 23). Nine of the 21 evaluated patients had little or no pain (defined as scores of 0-10) and as many as 13 had a low total score (defined as scores of 0-25). However, there were a few patients with considerable pain or with poor total scores. Thus, five of the 21 had pain scores of more than 50 or total scores of more than 50.

# Discussion

## Radiological evaluation

There are two distinct levels of answers desired when using diagnostic radiology in acute scaphoid fractures. The first level addresses the question "Is the scaphoid fractured?", and the second question is "What are the features of the fracture?" The present study has only dealt with the latter issue.

Since the first assessment of the fracture, and the clinical decisions deriving from that, are normally based on plain radiography, it is crucial that this investigation is of sufficient quality to identify risk factors for a poor outcome. Displacement and instability of the fracture constitute two such criteria where the risk of non-union and malunion is substantially higher compared to undisplaced fractures [29, 38, 42, 116]. Based on clinical experience, some scaphoid fractures exhibit significant deformity or displacement when assessed by CT, although this is not diagnosed on plain radiographs (Figure 7). This leads to the question as to whether or not the visual information on plain radiographs was sufficient to sort out the fractures that were displaced. Surprisingly few studies have compared plain radiographs with other image modalities in order to address this issue.

Other investigators have also reported difficulties in detecting displacement on plain radiographs. Bhat et al. assessed displacement by comparing MRI and plain radiography and found that only 3 of 9 fractures that were considered displaced were so identified on plain radiographs [16]. In an experimental setting it was shown that plain radiography and CT were equally sensitive in identifying displacement, although in different planes [115].

Dorsal lunate tilt has been reported to be an indirect sign of scaphoid fracture displacement [107] due to the tight interconnection of the proximal scaphoid fragment to the lunate via the interosseous ligament. In the present study this was not a reliable sign of acute scaphoid fracture displacement, and even severely displaced fractures had a normal radiolunate angle (Figure 8).

The present study has shown that if a strict protocol is utilized in the assessment, and the evaluation is performed by an experienced observer, it is possible to identify characteristics seen on plain radiographs that would prompt further investigation with CT.

One diagnostic aspect not dealt with in the individual papers of this thesis, but of contextual value, is assessment of the healing process as a basis by which to minimize treatment in cast. This problem complex is investigated very poorly, and so far there are no valid data to suggest a specific regime.

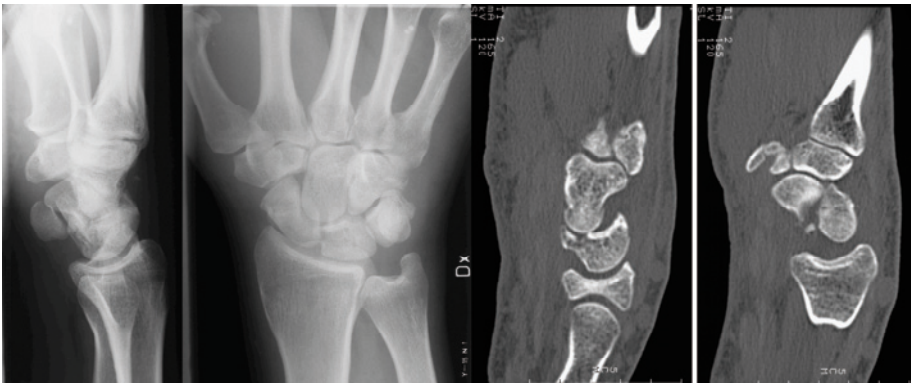

Figure 7. Scaphoid fracture with severe displacement seen on CT (right), although with minimal signs on plain radiographs (left).

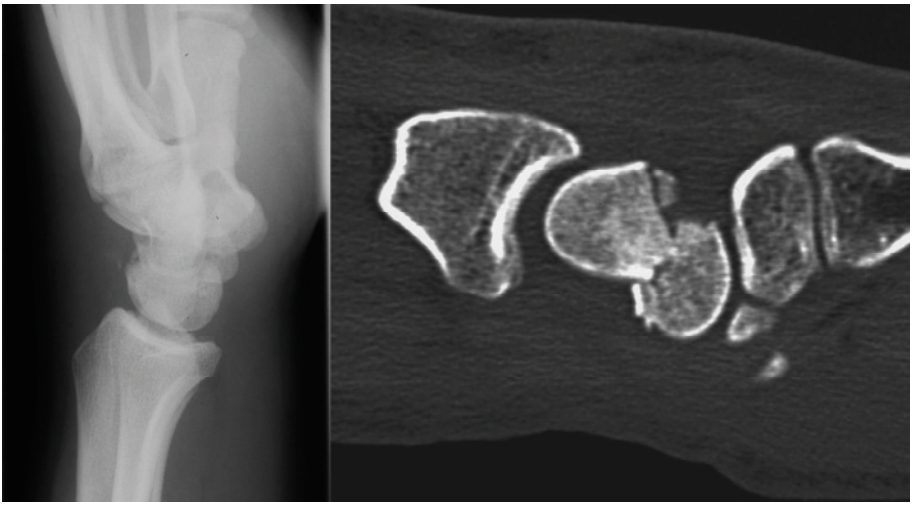

Figure 8. Scaphoid fracture with a normal radiolunate angle (left) in a patient with a severe fracture displacement.

## Treatment options. Which is best?

A recently published systematic review and meta-analysis of randomized and quasi-randomized trials evaluated the effect of operative versus nonoperative treatment and the effect of different casting methods in nonoperative treatment of acute scaphoid fractures [125]. Information was studied with

respect to non-union rate, return to work, grip strength, range of wrist motion, complications, patient evaluation, and incidence of osteoarthritis. The review concluded that operative treatment of acute nondisplaced or minimally displaced fractures of the scaphoid waist does not provide greater benefits regarding non-union rate, return to work, grip strength, range of wrist motion, or patient satisfaction than cast immobilization. However, it does cause more complications and, perhaps, a higher risk of scaphotrapezial osteoarthritis. The overall results of the metaanalysis are very similar to the results obtained in the present thesis. Above all, the increased risk for scaphotrapezial osteoarthritis suspected in the metaanalysis was corroborated in this thesis.

Yin et al failed to draw any conclusions about the optimal type of cast for conservative treatment [125]. In the present study the fractures of 41 of the 42 patients allocated to conservative treatment united while in a below elbow cast including the thumb, but leaving the interphalangeal joint free. The frequency of union, 98 %, is well in line with most other authors who report union rates of around 95 % [5, 74, 80], although a series with a 100 % union rate in cast has been published [101]. The median time in cast was 10 weeks (range 3-20). This is slightly higher than in other investigations and may be explained by the fact that in patients where assessment of union was difficult, prolonged immobilization was well accepted.

There are two key arguments for treating all or almost all scaphoid fractures operatively [28, 53, 54]. The first is that patients will have an immediate fracture stabilization which is beneficial for healing and which allows for early return to normal activity. The second is that preoperative assessment is insufficient for diagnosing the true nature of the fracture. Displacement and instability, two features that are strongly associated with poor outcome, are most safely diagnosed in the operating theatre. Assuming that those two key arguments play an important role for the final outcome after treatment of scaphoid fractures, it is reasonable to suppose that operated patients would exhibit clinical advantages in one or more aspects when assessed in randomized trials. With one exception, time in cast, this is not the case [125]. In fact, advantages of operative treatment other than the measured time in cast can only be expected in subgroups with a high risk for complications. Such patients are those with fractures with displacement defined as a significant gap or step-off between the fragments, and those with associated carpal instability defined as a scapholunate angle > 60° or a dorsal lunate tilt ≥15° [28, 29, 54, 112]. This perspective is based on reports of increased rates of non-union and malunion in this group of fractures [38]. Displaced fractures, as previously defined, are, however, reported to occur with a fairly low frequency [38]. In contrast to the overwhelming amount of literature recommending operative treatment for most fractures, one study has reported 100 % union in a series of 100 consecutive unselected scaphoid fractures treated conservatively in cast [101].

The role of "the intermediate fragment" has been poorly studied. It was recently pointed out that intermediate fragments regularly appear where there is late loss of bone and subsequent non-union [26]. The presence of such a fracture characteristic may signal a higher degree of trauma energy and thus an increased risk of fracture displacement or instability. In this study, the presence of an intermediate fragment on plain radiographs had a high sensitivity in detecting displacement or comminution as seen on CT.

As expected, and as dealt with elsewhere, those allocated to operative treatment in the present study had a shorter time in cast than those allocated to non-operative treatment. Except for that, there were no discernible advantages to operative treatment.

## Economic aspects – short-term effects

The present study is the first attempt to analyse health care economic consequences by means of a randomized approach in two different treatment modalities for scaphoid fractures. It was found that the major predictor of time off work and total health care cost was the socioeconomic status of the patient, and not the treatment mode. These findings were unexpected, since one of the main advantages of internal fixation is that a cast is rarely necessary and that normal activities can be commenced early. These claims were formulated before the Herbert screw came into frequent use [85]. On the other hand, in their systematic review Yin et al noticed surprisingly small differences between groups that were operated and those that were not [125].

Using a decision-analytic model based on data from the literature to calculate the outcomes and costs of open reduction and internal fixation and cast immobilization, Davis et al calculated that open reduction and internal fixation would be cost saving compared to casting from a societal perspective [31]. Their analysis was based on 10 weeks in cast in the one group and no cast at all in the other. They found that the late consequences in the form of secondary arthritis were actually less in the operated group than in the conservatively treated group. There was no analysis of the relation between type of work and inability to work while in cast.

In the present investigation those with non manual work had a significantly higher total cost if subjected to operative treatment. In a Swiss study Fusseti et al. [44] reported that 34% of the individuals treated conservatively could resume work with the wrist immobilized in a cast. Furthermore, Papaloizos et al.[98] reported that operative treatment using a minimally invasive technique was initially more expensive than conservative treatment, but markedly decreased the work compensation cost and was less expensive overall compared to treatment in plaster.

The present study largely corroborates the results of Saedén et al who reported that internal fixation with a Herbert screw resulted in shorter sick

leave than cast treatment, but this was only significant for “blue collar occupations”.

The health care system being considered also influences time off work. In the present study patients treated conservatively had a mean time off work of 71 days (median 74). In a similar study from the Netherlands, mean time off work was twice that figure, 144 days [120]. In the present study one third of the patients treated non-operatively could work with a plaster cast, while only 2 % did so in the Netherlands [120].

## Long-term consequences

For most patients the overall consequences of having a fractured scaphoid are minor. In the present study patients generally perceived themselves as having good upper limb and hand function 10 years after injury, although a subgroup had functional impairment. At this time, however, osteoarthritis was exhibited in the radiocarpal joint in 9 out of 74 patients and in the scapho-trapezial joint in 12 out of 74 patients. This risk is similar to that found by other authors [37, 76, 104]. There are indications that about half of those who develop osteoarthritis after a scaphoid fracture will develop symptoms after a longer time than the 10-year period in the present study [37].

In a previous randomized study with a 12-year follow-up in which the incidence of osteoarthritis was reported, the relative risk for scaphotrapezial joint osteoarthritis was 2.43 (95% confidence interval, 0.98–6.03) in those treated with an open osteosynthesis compared with those treated in cast. [104, 125] These controversial data are strongly supported by those of the present study, where the incidence of scaphotrapezial joint osteoarthritis was 11 out of 40 in the operated group and one out of 34 in the non-operative group.

The systematic review of Yin et al. clearly shows that the choice of treatment does not have an impact on range of motion. This information counteracts the earlier fear that individuals who are treated with immobilization in cast will develop stiff wrist joints [106]. The present study actually showed the opposite results: the individuals treated non-operatively in cast had numerically but not significantly better wrist movement and strength compared to those treated operatively.

Non-union constitutes the sole most significant clinical problem after scaphoid fractures and occurs in up to 10 % of cases. The most common reason for presenting with a non-union is that the individual never appeared for treatment in the acute phase [11]. The goal of treatment is to minimize the risk for development of a late osteoarthritis, something that is the rule without treatment [77, 102], even in patients who are initially symptom free. When bone preserving techniques utilizing osteosynthesis together with bone grafting have failed, implant arthroplasty or other reconstructive proce-

dures are indicated. In the present study it was found that many years after silicone implant arthroplasty, patients reported an acceptable hand function with little or no pain. These results point to the fact that there are currently acceptable treatment modalities for both early and late consequences of scaphoid fractures.

## Strengths and weaknesses

The strength of this thesis is above all the prospective randomized design, which had a direct impact on Papers II and III.

A weakness is the retrospective design of paper IV, although the items in the final patient assessments were in the present tense and concerned the present situation. In this study, the times for follow-up differed widely. Another weakness was that the economic measurements in Paper II were based on internal hospital price lists, which, from a formal perspective, are not validated. Furthermore, the time off work with economic compensation is the result of a truly subjective decision by the patient and doctor together, and is only partly dependent on a real inability to perform expected work tasks. On the other hand, these facts gave the study a naturalistic design.

# Conclusion

Based on our experience from this study we conclude that:

- A structural assessment of plain radiography images is highly predictive with respect to the risk of having a displaced or comminute fracture as diagnosed on computed tomography. Any finding of a gap or step-off > 0.5 mm, the presence of an intermediate fragment or a dorsal lunate tilt of ≥ 15° signals that the fracture should be investigated with a three dimensional technique.

- Individuals with an occupation that will hinder them from performing their duties while in cast are those most likely to benefit from internal fixation with respect to return to work and healthcare costs.

- Patients treated for scaphoid fractures generally do well 10 years after the injury based on limb specific outcome scores. There were no identified benefits with internal fixation compared to non-operative treatment in cast. On the contrary, there is an increased risk of developing osteoarthritis in the scaphotrapezial joint after internal fixation with the headless bone screw using the volar approach.

- Silicone implant arthroplasty provided pain relief and reasonable function in many patients, even after a long period of time.

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