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HUMERAL SHAFT FRACTURES

EPIDEMIOLOGY AND OUTCOME

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To the memory of my father, the best father anyone could possibly have

“So, so you think you can tell Heaven from Hell,
blue skies from pain.
Can you tell a green field from a cold steel rail?
A smile from a veil?
Do you think you can tell?

And did they get you to trade your heroes for ghosts?
Hot ashes for trees?
Hot air for a cool breeze?
Cold comfort for change?
And did you exchange a walk-on part in the war for a lead role in a cage?

How I wish, how I wish you were here.
We're just two lost souls swimming in a fish bowl, year after year.
Running over the same old ground.
What have you found? The same old fears.
Wish you were here.”

Roger Waters 1975

ABSTRACT

Humeral shaft fractures account for 1-3% of all fractures and approximately 20% of all humeral fractures. Non-operative treatment with functional bracing has been regarded as the golden standard for treatment of closed humeral shaft fractures with studies reporting a high overall healing rate and an acceptable functional outcome. Injury to the radial nerve in patients with humeral shaft fractures is the most common nerve lesion complicating fractures of long bones, and historically the Holstein-Lewis fracture, i.e. a simple spiral fracture in the distal third of the shaft, has been regarded as a strong indication for open reduction and internal fixation due to its association with radial nerve injury. However, there are only a few modern studies reporting the results after non-operative treatment, the outcome after primary radial nerve palsy and the outcome after a Holstein-Lewis fracture with a longer follow-up including patient-reported outcomes regarding function and the health-related quality of life (HRQoL).

The epidemiology of humeral shaft fractures in Stockholm was reported in a study comprising 397 consecutive patients with 401 fractures (*Study I*). It provided recent epidemiological data on humeral shaft fractures in a population with a limited amount of high-energy and penetrating trauma, probably reflecting a situation that prevails in most European countries. These data can be used to facilitate the planning of treatment for patients with this particular fracture.

In the sample of 397 patients, 78 consecutive patients at Södersjukhuset with a humeral shaft fracture initially treated non-operatively were identified (*Study II*). Data on fracture healing was collected from the medical charts. The patients were assessed prospectively regarding functional outcome and HRQoL. The study confirmed the high overall rate of union of humeral shaft fractures and an acceptable functional outcome after successful fracture-brace treatment. In simple fractures (Type A), the non-union rate seemed to be higher, and patients with healed non-unions after revision surgery had worse functional outcomes.

Thirty-three of the 397 patients with a humeral shaft fractures had primary radial nerve palsy (*Study III*). Data on the primary treatment modality, i.e. operative or non-operative, recovery of radial nerve function and fracture healing were collected from the medical charts. The patients were assessed prospectively regarding functional outcome and HRQoL. The study confirmed the high spontaneous recovery rate of primary radial nerve palsies in patients with closed humeral shaft fractures, regardless of the treatment modality. Primary radial nerve palsy should not be regarded as an isolated indication for primary surgical intervention.

Twenty-seven of the 397 patients with a humeral shaft fracture had a Holstein-Lewis fracture (*Study IV*). Data on the primary treatment modality, i.e. operative or non-operative, recovery of radial nerve function and fracture healing were collected from the medical charts. The patients were assessed prospectively regarding functional outcome. The study showed that the Holstein-Lewis humeral shaft fracture was associated with a significantly increased risk of primary radial nerve palsy. The overall outcome regarding radial nerve recovery, fracture healing and function was excellent regardless of the primary treatment modality, i.e. operative or non-operative. The indication for primary operative intervention in this specific fracture type appeared to be relative.

LIST OF PAPERS

This thesis is based on the following papers, which are indicated in the text by their Roman numerals (*Studies I-IV*).

I. FRACTURES OF THE SHAFT OF THE HUMERUS.
AN EPIDEMIOLOGICAL STUDY OF 401 FRACTURES.
Ekholm R, Adami J, Tidermark J, Hansson K, Törnkvist H, Ponzer S
J Bone Joint Surg [Br] 2006;88:1469-73

II. OUTCOME AFTER CLOSED FUNCTIONAL TREATMENT OF HUMERAL SHAFT FRACTURES.
Ekholm R, Tidermark J, Törnkvist H, Adami J, Ponzer S
J Orthop Trauma 2006;20:591-596

III. PRIMARY RADIAL NERVE PALSY IN PATIENTS WITH ACUTE HUMERAL SHAFT FRACTURES.
Ekholm R, Ponzer S, Törnkvist H, Adami J, Tidermark J
Submitted

IV. THE HOLSTEIN-LEWIS HUMERAL SHAFT FRACTURE. ASPECTS OF RADIAL NERVE INJURY, PRIMARY TREATMENT, AND OUTCOME.
Ekholm R, Ponzer S, Törnkvist H, Adami J, Tidermark J
Submitted

LIST OF ABBREVIATIONS

AO	Arbeitsgemeinschaft für Osteosynthesefragen
BG	Bone Graft
DASH	Disabilities of the Arm Shoulder and Hand
Fx	Fracture
HRQoL	Health-related Quality of Life
IF	Internal Fixation
IM	Intramedullary
IMN	Intramedullary Nailing
NMM	Nottingham Mecmesin Myometer®
ORE	Olavi Radford Ekholm
OTA	Orthopaedic Trauma Association
RCT	Randomised controlled trial
SF-36	Short Form-36
SMFA	Short Musculoskeletal Function Assessment
SPSS	Statistical Package for the Social Sciences

INTRODUCTION

BACKGROUND

Humeral shaft fractures account for 1-3% of all fractures[6,53,89] and approximately 20% of all humeral fractures,[72] but little is known about additional epidemiological data on this specific fracture type. To the best of our knowledge, there has been only one previous epidemiological study, the one by Tytherleigh-Strong *et al.*, describing the epidemiology of 249 humeral shaft fractures in Edinburgh during 1989-92[88] *(Study I).*

Historically, functional bracing has been the treatment of choice for closed humeral shaft fractures with studies reporting a high overall healing rate and an acceptable functional outcome.[45,77,95] However, there are only a few modern studies reporting the results of non-operatively treated patients with humeral shaft fractures with a fairly long follow-up including patient-reported outcomes regarding function and the health-related quality of life (HRQoL)[45,69,77,79] *(Study II).*

Injury to the radial nerve is the most common nerve lesion complicating fractures of long bones.[81] In open fractures of the humeral shaft, exploration of the nerve is recommended at the time of fracture fixation, i.e. nearly always acutely. [24,70] In closed fractures with associated radial nerve injury, the primary treatment is still a matter of dispute. Some authors recommend early exploration of the radial nerve,[19,40,64] while others advise against it. [4,43,48,66,76,80,82,84] In a recent systematic review based on 21 observational studies, Shao *et al.* reported an overall incidence of radial nerve palsy of 11.8%.[81] There was no significant difference in the final results on comparing patients initially managed non-operatively with those explored early on, suggesting that the initial non-operative treatment did not affect the recovery of the nerve adversely. However, none of the previous studies have reported the results in terms of general disability or HRQoL, nor has any previous study analysed the outcome within a defined population of consecutive patients *(Study III).*

The Holstein-Lewis humeral shaft fracture is well known to most orthopaedic surgeons. This particular fracture, i.e. a simple spiral fracture in the distal third of the shaft with the distal bone fragment displaced and its proximal end deviated towards the radial side, was originally described by Arthur Holstein and Gwilym Lewis in the American Journal of Bone and Joint Surgery in 1963.[40] They initially presented seven cases with this type of fracture associated with radial nerve palsy. In a subsequent study 341 consecutive fractures were reviewed and six patients with radial nerve palsies were found, five of whom showed this specific fracture pattern. The authors hypothesized that the reason for this seemingly high association with radial nerve palsy was that the fracture occurs at a point where the radial nerve runs through the lateral intermuscular septum and lies in direct contact with the bone and has limited mobility. Due to the force of the injury the distal fragment is moved proximally and radially, potentially lacerating or trapping the radial nerve. The overall conclusion drawn by the authors was that open reduction and internal fixation should be regarded as the treatment of choice for this type of injury. In a systematic review of radial nerve palsy associated with humeral shaft fractures, Shao *et al.*[81] found only two papers[44,51] presenting data on the Holstein-Lewis fracture. They concluded that the specific relationship between the

Holstein-Lewis fracture and radial nerve palsy is probably not as strong as the original authors concluded.[40] However, none of the previous studies have reported the long-term functional outcome in relationship to primary treatment, i.e. operative or non-operative, or analysed the outcome within a defined population of consecutive patients (*Study IV*).

EPIDEMIOLOGY

Epidemiology is defined as “the study of the distribution and determinants of disease frequency”[74] – in short, “the study of the occurrence of illness”.[38] *Clinical* epidemiology, on the other hand, focuses on the consequences of the condition and the care given for it – i.e. “the study of variation in the outcome of illness and of the reasons for that variation”.[93] The methods are similar in epidemiological research as a whole and in clinical epidemiology – observations are made on a patient with a specific illness (e.g. a humeral shaft fracture) and what characterizes other patients without this particular illness. Conclusions can then be drawn regarding differences in outcome. This may sound simple, but, in practice, correct results may be difficult to obtain without proper training in epidemiological concepts and methods. By using epidemiological methods, the health consequences of, e.g. a specific therapy, can be accurately measured and this information should be the foundation on which treatment and resource allocation should be based. For a study to be able to display the true epidemiology of a certain type of fracture, it has to include all patients with this specific fracture type occurring within a defined population during a defined period of time. Sociodemographic background data also have to be accessible. The Swedish personal identification number system renders it possible to identify virtually all citizens in Sweden, thus defining the population with great accuracy. Since most of the hospitals in Sweden have computerized radiological databases and medical records, patients can be identified by reviewing the results of radiographs in the computer files at the different hospitals, and background data, e.g. injury mechanism, age, gender, side of the injury, occurrence of possible complications and results, can then be collected from the medical charts.

ANATOMY

The humerus (latin, *upper arm)* is, after the femur and the tibia, the third largest long bone. It articulates proximally with the glenoid cavity of the scapula in the shoulder joint, and distally with the ulna and the radius in the elbow joint. Removing a square, whose sides are the same length as the widest part of the epiphysis, from the proximal and distal end of the humerus leaves us the part of the humerus defined as the shaft. The humeral shaft extends proximally from the upper border of the pectoralis major tendons insertion to the supracondylar ridge distally (Figure 1). For reasons of classification, the humeral shaft can then be further divided into three equally long parts: the proximal, middle and distal parts of the shaft.

Figure 1
The ventral aspect of the right humerus.

The soft tissues of the arm are divided into the anterior and the posterior compartment by the medial and lateral intermuscular septa. The anterior compartment consists of the biceps, coracobrachialis, brachialis and anconeus muscles, the brachial artery and vein, and the median, musculocutaneous and ulnar nerves. The posterior compartment consists of the triceps muscle and the radial nerve.

Injury to the radial nerve is the most common nerve lesion complicating fractures of long bones.[81] A radial nerve injury clinically expresses itself as a "radial palsy" or "wrist drop" with an inability to extend the wrist and the metacarpophalangeal joints (Figure 2), and a sensory disturbance of the dorsolateral forearm and hand. The radial nerve, containing both sensory and motor components, is the largest branch of the posterior cord of the brachial plexus containing cervical root contributions from C5-8 and usually exits the lateral intermuscular septa from the posterior compartment directly distal to the middle of the humeral shaft, which is approximately 10 cm proximal to the radial epicondyle. The close relationship of the radial nerve to the humeral shaft and its limited mobility in that area makes it vulnerable. Branches from the brachial artery supply the humeral shaft with blood.

Figure 2
Radial palsy.

NON-OPERATIVE TREATMENT

SPLINTING, PLASTER CAST, FUNCTIONAL BRACING

Closed humeral shaft fractures caused by low-energy trauma are historically treated non-operatively, which is considered to be a simple, reliable, safe and effective method with few complications.[45,77,79,95]

The first known examples of active non-operative fracture treatment are the findings of a splinted femur and forearm in two specimens found by Professor Elliot Smith during the Hearst Egyptian Expedition in 1903.[83] Different kinds of precursors to the modern plaster bandage are known to have been used as far back as AD 860, but it was not until 1876 that Antonius Mathijsen,[56] a military surgeon, introduced a plaster bandage that resembles the ones used today. In 1517, Gersdorf[25] demonstrated a new technique for binding wooden splints and, in 1767, Benjamin Gooch[26] plagiarized this method in describing the first functional brace. His ideas remained virtually obscure until 1967 when Sarmiento[78] renewed the interest in functional bracing and, with the development of plastic materials and ready-made braces, this technique has gained widespread acceptance in the treatment of humeral shaft fractures.

OPERATIVE TREATMENT

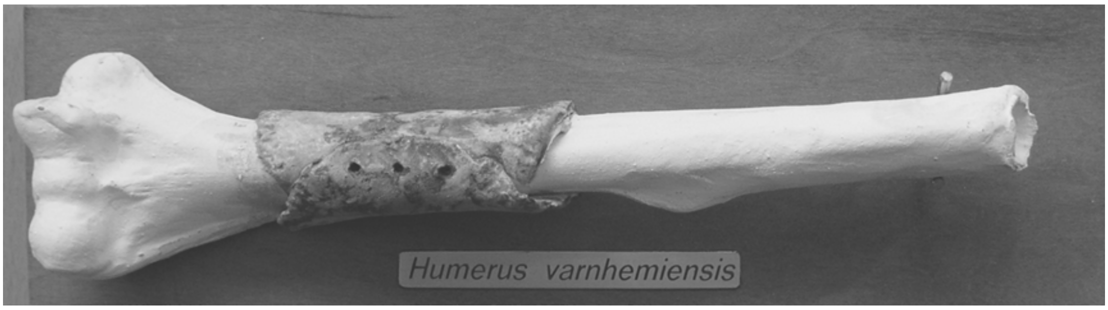
Generally accepted indications for *acute operative treatment* include multiple trauma, segmental or bilateral fractures, combination with a forearm fracture ("floating elbow"), pathological fractures and some fractures caused by high-energy trauma, including open fractures with nerve and/or vascular injuries and obesity.[59,89] Improved fracture reduction, more stable fixation, easier and less painful mobilisation are, historically, indications for internal fixation. In recent years, owing to the development of new implants, e.g. angle stable screws, and operative techniques, acute operative treatment has gained increasing interest, even for patients with isolated simple humeral shaft fractures.[12,19,37] Other studies have indicated that operative treatment is more hazardous due to an increased risk of infection, radial nerve palsy, shoulder impingement, delayed union and non-union.[23,59]

Elective operative treatment has been recommended for initially nonoperatively treated patients with persisting or increasing nerve dysfunction and/or nonunion.[59] A malunited fracture is rarely an indication for surgical correction[59,77] since a varus angulation of 30º, an anterior angulation of 20º, a malrotation of 15º and a shortening of 3 cm of the humerus can be accepted without compromising function or appearance.[89]

PLATE FIXATION

Presumably the earliest known osteosynthesis of a humeral shaft fracture was successfully performed with a surrounding copper plate (Figure 3**)**. The specimen was found in the monastery of Varnhem in Sweden in about 1928, and the bone is dated somewhere between the years 1250 and 1527.[33]

Figure 3
The humerus found in Varnhem.



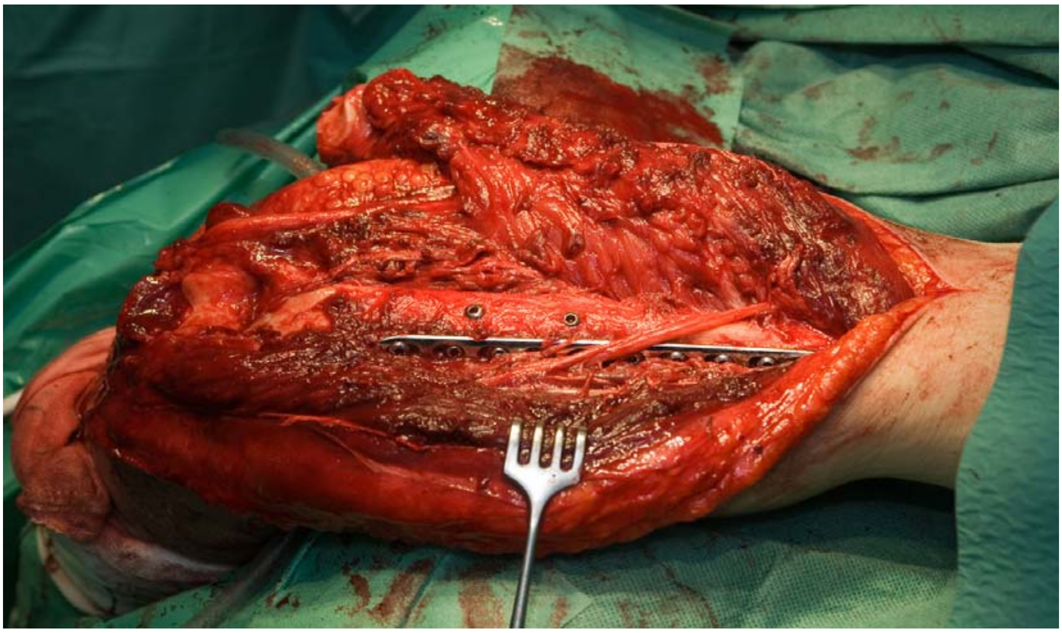
The first modern account of plate fixation was probably a report by Hansmann in Hamburg in 1886.[34] He used a malleable angled metal plate and special screws that projected through the skin for easy removal. At the beginning of the 20th century Estes used a nickel steel plate fixed to the bone with ivory pegs, and Steinbach is reported to have used silver plates at about the same time.[30] Alain Lambotte (1866-1955) in Belgium coined the term osteosynthesis and is regarded as the father of internal fixation.[17] He developed plates for rigid bone fixation in a variety of materials. Sir William Arbuthnot Lane (1856-1943) in London, the other pioneer of internal fixation, also constructed his own plates and was active in developing new antiseptic techniques.[49] Robert Danis (1880-1962) of Brussels developed the concept of stable internal fixation to permit immediate functional rehabilitation. A young Swiss surgeon, Maurice Müller, was influenced by Danis and inspired a group of colleagues to gather a study group for the development of internal fixation, and so the AO (Arbeitsgemeinshaft für Osteosynthesefragen) was formed in 1958. The original AO principles where those of anatomical reduction, rigid fixation, early mobilisation and atraumatic handling of the soft tissues, but they have developed continuously towards a more biological approach. The plates, which initially were thick and wide with screws that only gave axial compression, are now slim with limited contact with the bone and with the possibility of angle-stable screws, which greatly improves the stability of fractures, especially in osteoporotic bone. Methods of indirect reduction and minimally invasive percutaneous osteosynthesis have been developed. Bridging plates, i.e. plates that are fixed to the bone only proximal and distal to the fracture, are used in complex fractures in an attempt to spare the bone vascularity and thus increase the possibilities of healing. In summary, the evolutions of plates has provided the orthopaedic community with new and improved implants, but they are just implants and will not suffice without the modern principles of fracture treatment.

There are mainly three surgical approaches in open plating of humeral shaft fractures. The approaches for minimally invasive surgery are not described here.

The *anterolateral approach* can be used for fractures of the whole humerus, but it is mostly used for fractures of the proximal and middle thirds of the shaft. The patient is placed in a supine position. The skin incision can extend from just distal to the coracoid process and continue along the deltopectoral groove and the lateral border of the biceps down to the elbow. The humerus is exposed proximally between the deltoid and the pectoralis major muscles, continuing distally with a longitudinal dissection through the brachialis muscle. Usually, the radial nerve is not exposed, but is protected as it runs laterally between the brachialis and brachioradialis muscles after leaving the lateral intermuscular septum.

The *posterior approach* is used in fractures of the distal third of the shaft and gives excellent exposure of the radial nerve. The patient is placed in a lateral position with the arm abducted 90º over an elbow rest. The skin incision is straight and can extend from the posterolateral edge of the acromion to the tip of the olecranon. The humerus is exposed by splitting the triceps muscle proximally and its tendon distally. The radial nerve must be identified as it crosses the path of the incision in the distal half of the humeral shaft (Figure 4).

Figure 4
The posterior approach on a right humerus with the radial nerve exposed.



The *lateral approach* gives access to the middle third of the humeral shaft, but it can also be extended proximally and distally to expose the whole length of the humerus. It gives excellent exposure of the radial nerve. The patient is placed in a supine position, and the skin incision can begin from the insertion of the deltoid muscle proximally and runs laterally of the brachioradial muscle to the elbow. The humerus is exposed between the brachial muscle medially and the triceps and the brachioradialis muscles laterally. The radial nerve is identified distally between the brachial and brachioradial muscles and can then be followed in a proximal direction.

INTRAMEDULLARY NAIL FIXATION

Intramedullary nails made of various materials like silver and ivory were used in fractures of the femoral and humeral neck at the end of the 19th century. The use of rods in the intramedullary cavities of the long bones was recommended by Lambrinudi in 1940,[47] and the method was improved by the Rush brothers in the United States.[75] The modern technique of using elastic nails was developed by Professor Küntcher in Germany and presented in his first book on the subject at the end of the Second World War.[46]

An intramedullary nail in the humerus can be inserted using either an antegrade or retrograde technique. As a rule, fracture reduction is accomplished using closed methods, but if open reduction is warranted, the surgical approaches are the same as in plate fixation.

When using an *antegrade* intramedullary nail, the patient is placed in a beach chair position. The skin incision is anterolateral to the acromion, not extending farther than 4 cm distally to avoid injury to the axillary nerve. The deltoid muscle is split longitudinally, and the supraspinatus tendon is split in the direction of its fibres, exposing the entry point for the nail, which is usually placed just medial to the greater tuberosity. If reaming is indicated, it is important that contact between the fracture fragments is achieved prior to reaming, so as not to risk injury to the radial nerve. The nail is then inserted and gently passed distally, ensuring not to distract the fracture, since this can lead to injury of the radial nerve and impaired fracture healing. The proximal end of the nail should be inserted below the surface of the humeral head to avoid impingement. To achieve rotational stability, the nail should be locked proximally and distally. The distal interlocking screws should be positioned using careful blunt dissection to ensure that the radial, median and musculocutaneous nerves and the brachial artery are not compromised.

A *retrograde* nail can be used in fractures of the middle and distal parts of the humeral shaft. The patient can be placed either in a supine, prone or lateral position. The posterior cortex of the distal humerus is exposed using a triceps split incision, and an opening is made approximately 2 cm above the olecranon fossa. The modus operandi is then the same as for antegrade nailing

EXTERNAL FIXATION

The first external fixation device was demonstrated by Malgaigne in 1840[9] and consisted of a hemicircular metal arc strapped to a limb with a screw that could press any projecting fragment into reduction. At the end of the 19th century, Keetley, in London, described the first external fixator that was implanted into the full diameter of the bone.[42] The first modern type of external fixating device was documented by Parkhill in Denver in 1897.[65] Hoffman in Geneva developed his own system with early results published in 1938,[39] but it was not until the 1960s that Vidal and co-workers started to develop the biomechanical principles on which external fixation was based.[94]

To facilitate the correct placement of external fixation pins in humeral shaft fractures, the humerus can be divided into 4 equally long zones, A–D, from proximally to distally.[27] Pins should be inserted under direct visualisation to avoid damage to neurovascular structures. In zones A–B, pins should be placed from a lateral position, with special care below the surgical neck of the humerus to avoid injuring the circumflex vessels and the axillary nerve. In zone C, the pins should be placed in the same manner with care not to injure the radial nerve. In zone D, the pins should be positioned from a posterior approach.

Figure 5
Examples of surgical methods. From left to right: plate, antegrade and retrograde intramedullary nails and external fixation.

METHOD OF TREATMENT AND INDICATION

ACUTE OPERATIVE TREATMENT

Generally accepted indications for acute operative intervention in humeral shaft fractures include multiple trauma, segmental and bilateral fractures, floating elbow, pathological fractures, open fractures and fractures with vascular injuries.[59,89] Indications for external fixation are limited to severe open fractures and infected non-unions - usually as a temporary treatment until definitive treatment with internal fixation can be performed.[13,27]

Our interpretation of the current literature favours plating in the majority of the acute indications presented above,[14,15,52,57,59,71] except for segmental fractures and multiple trauma patients, where the fracture configuration and time aspect, respectively, probably make nailing the preferred method.[57,59] Intramedullary nailing, sometimes reinforced with bone cement, is also the treatment of choice in most patients with pathological fractures. These patients pose significant challenges partly due to the fact that pathological fractures almost never heal, regardless of the treatment modality.[92]

A recent meta-analysis compares compression plating to intramedullary nailing in patients with humeral shaft fractures[10] Bhandari *et al.* found only three papers satisfying the criteria for the meta-analysis.[15,57,71] These papers involved 155 patients, the vast majority with closed fractures. All three papers favoured plate fixation and the pooled results showed that plate fixation carried a significantly lower relative risk of reoperation than intramedullary nailing (RR = 0.26, 95% CI 0.007–0.9) and also a reduced risk of shoulder problems (RR=0.10, 95% CI 0.03-0.4). In newly published Orthopaedic Trauma Directions,[1] evidence from 3 randomized controlled trials[14,15,57] suggested that treatment of acute humeral shaft fractures with intramedullary nailing (IMN), compared to plate fixation, leads to comparable results with respect to rates of non-union, infection and iatrogenic nerve injury, but an increased risk of reoperation with IMN.

NON-UNION

Most surgeons agree that a humeral shaft fracture should unite within 3–4 months or else be regarded as a non-union. The most effective way to heal a non-union is by operative intervention. Our interpretation of the current literature strongly favours plating in nearly all patients with non-unions.[18,22,36,73] Simultaneous bone-grafting or osteoinductive bone substitutes may be indicated depending on the type of non-union, i.e. the degree of biological activity.

CLOSED HUMERAL SHAFT FRACTURES

Most closed humeral shaft fractures are managed non-operatively, i.e. with closed functional bracing. However, there are studies indicating that the incidence of non-union after non-operative treatment is higher in selected fracture patterns,[20,61] and that far from all patients are fully recovered after non-operative treatment.[45,77] Moreover, a good outcome after plate fixation has been reported in patients with selected indications,[57] and there have been major improvements in the plating technique in recent years, e.g. angular stable screws.[8,12,19,31,32,37,61] Despite these circumstances, there have been so far no randomised controlled trials (RCTs) comparing closed functional bracing with primary plate fixation in patients with closed humeral shaft fractures. Based on the previously presented comparisons between plating and nailing and according to the current data, there is, in our opinion, no need for a RCT comparing closed functional bracing with intramedullary nailing.

AIMS OF THE STUDIES

STUDY I

To investigate the epidemiology of humeral shaft fractures in adults.

STUDY II

To investigate the outcome of a consecutive series of patients with isolated humeral shaft fractures treated primarily non-operatively.

STUDY III

To report on the recovery of radial nerve function in patients with acute closed humeral shaft fractures and associated primary radial nerve palsy in relation to treatment modality, i.e. operative or non-operative. To report on the long-term functional outcome and health-related quality of life in patients with this particular injury.

STUDY IV

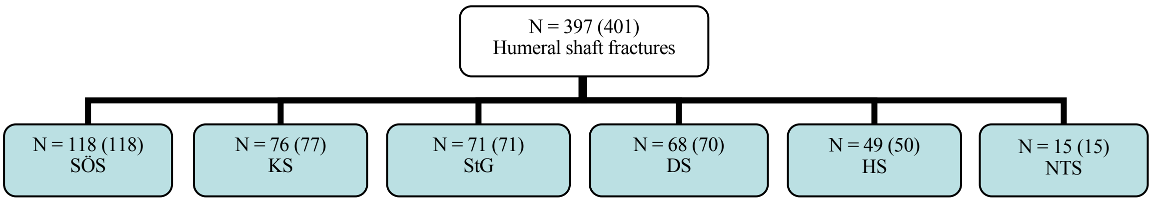
To describe the epidemiology of the Holstein-Lewis humeral shaft fracture, its association with radial nerve palsy and the outcome regarding recovery from the radial nerve palsy and fracture healing. To analyse the long-term functional outcome in patients with this particular injury.

PATIENTS AND METHODS

STUDY I

All patients aged 16 years or more admitted to any of the six major hospitals in the County of Stockholm (SÖS, KS, HS, DS, StG, NTS[1]) between 1 January 1998 and 31 December 1999 with fractures of the shaft of the humerus were retrospectively identified from computer files in the radiological departments of each hospital and included in this study. A total of 401 fractures were found in 397 consecutive patients (Figure 6). Three hundred and sixty-one of the fractures were classifiable according to the Orthopaedic Trauma Association (OTA) system.[62,63] The remaining 40 fractures were pathological (n=34) or peri-implant fractures (n=6) and therefore not classified. Open fractures were classified using the Gustilo[28,29] system. Background data were retrieved from the medical charts.

Figure 6
Flow chart of the patients (number of fractures) in *Study I*.

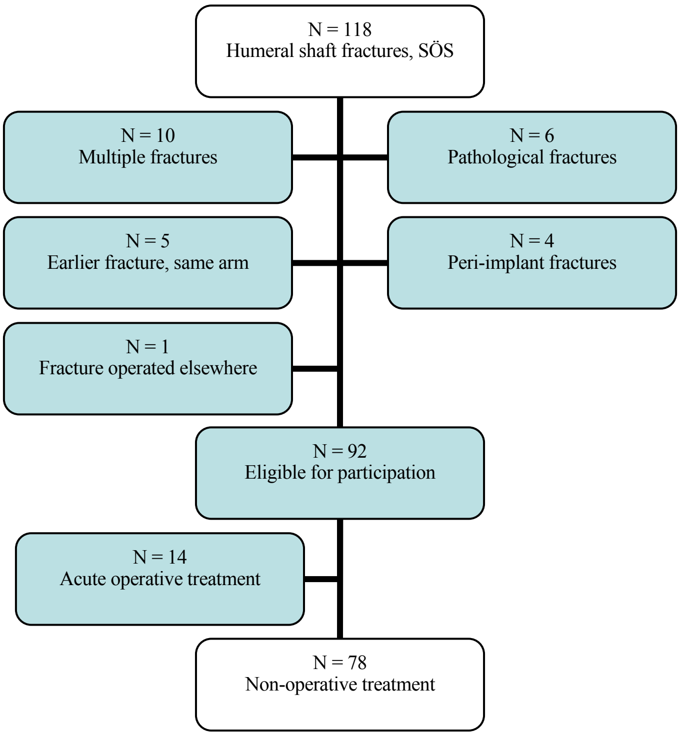


[1] SÖS = Södersjukhuset, KS = Karolinska Universitetssjukhuset Solna,
HS = Karolinska Universitetssjukhuset Huddinge, DS = Danderyds Sjukhus,
StG = Capio S:t Görans Sjukhus, NTS = Norrtälje Sjukhus

STUDY II

All 118 patients from *Study I* admitted to SÖS during the study period were identified. Ninety-two patients satisfied the inclusion criteria of having an acute, non-pathological humeral shaft fracture in a previously uninjured arm. Fourteen patients underwent acute operative treatment based on the treating surgeon's preference, leaving 78 patients treated non-operatively primarily in the study group (Figure 7).

Figure 7
Flow chart of the patients in *Study II*.



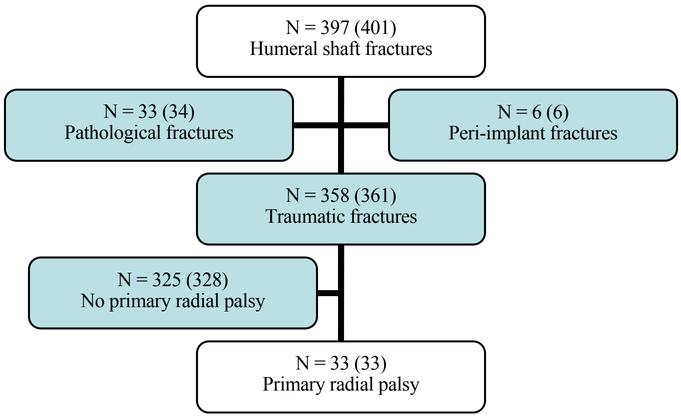
Eight of these 78 patients developed a non-union, and these patients were later treated operatively. The fractures were classified according to the OTA classification. Background data including injury mechanism, treatment modalities, fracture healing and fracture-related complications were collected from the medical charts and were available for all patients.

All 78 patients were contacted a minimum of 12 months after the injury for a follow-up. Fifty patients were eligible for the final follow-up, but one patient had persisting non-union and was excluded from the assessment of functional outcome, leaving 49 patients (63%) in the final assessment that was performed with a mean of 26 months after the fracture. The patients rated their musculoskeletal functional status according to the Short Musculoskeletal Function Assessment (SMFA)[67,86] and their health-related quality of life (HRQoL) according to Short Form 36 (SF-36).[16,35,85,90,91] Additionally, the patients were asked to state if they considered themselves recovered after the humeral shaft fracture.

STUDY III

Of the 397 patients in *Study I*, thirty-three had primary radial nerve palsy and were included in the study (Figure 8).

Figure 8
Flow chart of the patients (number of fractures) in *Study III*.



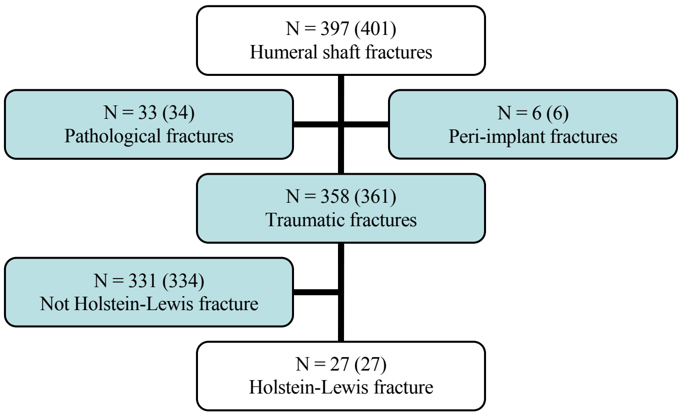
Treatment was carried out as per the decision of the attending orthopaedic surgeon. Primary operative treatment was performed in 15 patients (45%). The other 18 patients (55%) were treated non-operatively primarily. The fractures were classified according to the OTA classification. Data on age, gender, side of the injury, injury mechanism, treatment modality, clinical recovery from the radial nerve palsy and fracture healing were available for all patients.

All 33 patients with primary radial nerve palsy were contacted at a minimum of 70 months after the injury for a follow-up. Sixteen patients (48%) – eight operatively and eight non-operatively treated - were available at the final follow-up regarding long-term functional outcome and HRQoL at a mean of 84 months after the injury. Follow-up included an assessment of range of motion (ROM) of the shoulders, elbows and wrists; muscular strength of the shoulders and handgrip, and a neurological examination of the arms. The patients also rated their musculoskeletal functional status according to the SMFA and the Disabilities of the Arm, Shoulder and Hand (DASH) scoring system[5,7,41] and their HRQoL according to SF-36. The SMFA values were compared to those of a reference population from *Study II* with a healed humeral shaft fracture without radial nerve palsy.

STUDY IV

Of the 397 patients in *Study I*, 27 had a type 12A1.3 fracture satisfying the criteria of a Holstein-Lewis fracture, i.e. a simple spiral fracture in the distal third of the shaft with the distal bone fragment displaced and the proximal end deviated towards the radial side, and were included in the study (Figure 9).

Figure 9
Flow chart of the patients (number of fractures) in *Study IV*.



Data on age, gender, side of the injury, injury mechanism, treatment modality, clinical recovery from the radial nerve palsy and fracture healing were available for all patients. Treatment was carried out as per the decision of the attending orthopaedic surgeon. Comparisons regarding background data were made between operatively and non-operatively treated patients in the study group, as well as between the 27 patients with a Holstein-Lewis fracture in the study group and the 331 patients with other fracture types (Figure 5). Eighteen patients (67%) were available at the final follow-up regarding the long-term functional outcome at a mean of 83 months after the injury. Follow-up included an assessment of range of motion (ROM) of shoulders, elbows and wrists; muscular strength of the shoulders and handgrip, and a neurological examination of the arms. The patients also rated their musculoskeletal functional status according to the SMFA.

FRACTURE CLASSIFICATION

The fractures were classified according to the OTA classification system.[62,63] Open fractures were also classified using the Gustilo classification system.[28,29]

OTA CLASSIFICATION

The OTA classification is based on the AO classification system developed by Müller *et al.*[60] The fracture type is expressed by combining the numerical code of its location with the alphanumerical code of its morphological characteristics. The system was developed to facilitate computer storage and retrieval. We opted to classify all fractures, even Type C fractures, in 5 levels with the last digit referring to the localization on the shaft. Two examples of how the classification should be read:

Fracture Type **12 C3.2**

1 refers to the bone – in this case, the humerus.
2 refers to the segment – in this case, the diaphysis.
C refers to the basic fracture pattern – in this case, a complex fracture.
3 refers to subgroup of pattern – in this case, an irregular fracture.
2 refers to the localization within the segment – in this case, a fracture in the middle third.

Fracture Type **12 A1.3** (Figure 10)

1 refers to the bone – in this case, the humerus.
2 refers to the segment – in this case, the diaphysis.
A refers to the basic fracture pattern – in this case, a simple fracture.
1 refers to subgroup of pattern – in this case, a spiral fracture.
3 refers to the localization within the segment – in this case, a fracture in the distal third.

Figure 10
The Holstein-Lewis fracture (12A1.3)

GUSTILO CLASSIFICATION

The Gustilo classification was originally developed for classification of open fractures of the tibia and femur, but it is now commonly used for all open fractures. Gustilo *et al*. classify open fractures into three basic types (Type I–III) with increasing severity as to the degree of soft tissue injury. Type III is then further divided into the three subgroups (A–C) with increasing severity (Table 1).

Table 1
The Gustilo classification of open fractures.

Type I	Skin opening of 1 cm or less, quite clean. Most likely from inside to outside. Minimal muscle contusion. Low-energy injury.
Type II	Laceration more than 1 cm long, with extensive soft-tissue damage, flaps, or avulsion. Minimal to moderate crushing component.
Type III	All grade III injuries are caused by high-energy trauma.
Type III A	Extensive soft-tissue laceration may occur, but the bone is covered by soft tissue after reduction of the fracture.
Type III B	Extensive soft-tissue injury with periosteal stripping and bone exposure. Usually associated with massive contamination. Bone may be lacking. Impaired soft tissue not able to completely cover the bone. Plastic surgery is often required.
Type III C	Vascular injury requiring repair.

CLINICAL EXAMINATION

RANGE OF MOTION (ROM)

The active ROM was measured with a standard goniometer and the result was expressed as the percentage of the result for the uninjured arm (*Studies III and IV*). The ROM of the shoulder and elbow was measured with the patient standing and the ROM of the wrist with the forearm resting on a table. Shoulder flexion and abduction was measured with the thumb pointing up, external rotation with the arm in 0º of abduction and internal rotation with the arm in 90º of abduction. The average ROM according to McRae in "Clinical Orthopaedic Examination"[58] is presented in Table 2.

Table 2
The average ROM according to McRae.

Shoulder	Flexion (Forward) 0-165º	Extension (Backwards) 0-60º
	Abduction 0-170º	
	External rotation 0-70º	Internal rotation 0-70º
Elbow	Flexion 0-145º	Extension 0º
	Pronation 0-75º	Supination 0-80º
Wrist	Flexion 0-75º	Extension 0-75º

STRENGTH

The strength of the shoulders in 45º of abduction was tested with the Nottingham Mecmesin Myometer® and the strength of the handgrip was measured with the Jamar Hydraulic Hand Dynamometer®. The results were expressed as the number of kilograms for the injured arm subtracted from the number of kilograms for the uninjured arm. We did not correct for hand dominance (*Studies III and IV)*.

SENSIBILITY

Sensibility of the arm was tested for light touch and a sharp pin-prick and was categorized as normal, impaired or hyperaesthetic (*Studies III and IV*).

INJURY MECHANISM

The injury mechanisms (*Studies I–IV*) were classified as simple fall, fall from height, traffic-related accident, sport-related and miscellaneous (e.g. assault and pathological fractures). A simple fall was defined as falling at the same level and a fall from height as falling from a higher level, including falls on stairs and from furniture.

The energy grade was assessed individually in all cases and reported as high-energy or low-energy. All simple falls and the vast majority of sport-related injuries were graded as low-energy ones while most falls from heights and almost all traffic-related accidents were graded as high-energy ones.

MUSCULOSKELETAL FUNCTION STATUS

The instruments used to investigate the patients musculoskeletal function status were the SMFA[67,86] (*Studies II–IV*) and the DASH[5,7,41] (*Study III*). Additionally, the patients were also asked to state if they considered themselves recovered after the humeral shaft fracture (*Study II*). The SMFA, DASH and the additional question are in the form of self-administered questionnaires and were sent to the patients before the scheduled follow-up.

SHORT MUSCULOSKELETAL FUNCTION ASSESSMENT (SMFA)

The SMFA is an outcome instrument designed to measure the functional status of patients with a wide range of musculoskeletal injuries and disorders. It has been validated for use in Sweden.[67] The SMFA score comprises 46 items summed into the Dysfunction Index and the Bother Index. The Dysfunction Index assesses perceptions of the amount of difficulty the patients experience in their performance of certain functions and how often there are difficulties when performing certain functions. The dysfunction items are grouped into four categories: daily activities, emotional status, function of the arm and hand, and mobility. The Bother Index asks the patients to assess how much they are bothered by problems in different areas of life (for example, recreation, work, sleep and rest). The scores of the Dysfunction and Bother Indexes are calculated by summing up the responses to the items and then transforming them into the final scores, ranging from 0 to100. A higher score indicates a poorer function and consequently a score of 0 indicates that the patient has completely normal function with no musculoskeletal problems

DISABILITIES OF THE ARM, SHOULDER AND HAND (DASH)

The DASH is a region-specific outcome instrument for evaluating upper extremity disability and symptoms. It has been validated for use in Sweden.[5] The main part is a 30-item disability/symptom scale concerning the patient's health status during the preceding week. The DASH also contains two optional 4-item scales (not used here) concerning the ability to perform in sports and/or to play a musical instrument and the ability to work. Each item has 5 response choices, ranging from "no difficulty or no symptoms" to "unable to perform activity or very severe symptoms", scored on a 1–5 point scale. The scores for all items are then used to calculate a scale score - the DASH score - ranging from 0 to 100. A higher score indicates greater disability.

QUALITY OF LIFE

The quality-of-life instrument used was the SF-36[16,35,85,90,91] (*Studies II and III*). It is a self administered questionnaire and was sent to the patients before the scheduled follow-up.

SHORT FORM 36 (SF-36)

The SF-36 is a health-related quality-of-life rating instrument comprising 36 statements concerning functional ability, well-being and overall health. The SF-36 has been widely used and its validity and reliability have been shown to be acceptable in a Swedish population. The results for 35 of the 36 questions are aggregated into 8 subscores (i.e. physical functioning, role limitations due to physical function, bodily pain, general health, vitality, social functioning, role limitations due to emotional problems and mental health). The raw values of the eight subscores are transformed and the final subscores for each category range from 0 to 100 (100 optimal).

TREATMENT

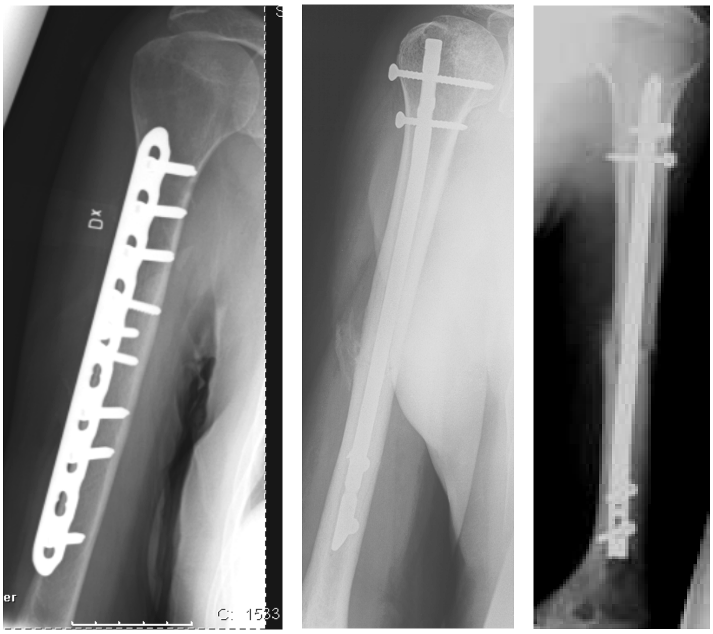
The non-operative treatment employed was closed functional treatment (Figure 11). The patients were provided with a fracture brace or, initially, a splint followed by a fracture brace, and a collar-and-cuff sling.

Figure 11
Prefabricated fracture brace.

Sarmiento, JBJSAm 2000; p 479

The method of operative treatment was as per the decision of the attending orthopaedic surgeon at each hospital. The treatment options were open reduction and internal fixation (ORIF) with plates or closed/open reduction and fixation with an ante- or retrograde intramedullary nail (Figure 12). In a single case, only lag-screws were used for fixation (not recommended). Additional bone-grafting was used in some patients with non-union.

Figure 12
Left to right: plate, antegrade and retrograde intramedullary nail.



STATISTICAL METHODS

The statistical software used was SPSS 13.0 (*Studies I and II*), SPSS 14.0 (*Study III*) and SPSS 15.0 for Windows (*Study IV*) (SPSS Inc., Chicago, Illinois).

In *Study I* the independent samples t-test was used for scale variables in independent groups and nominal variables were tested using the Chi-square test. All tests were two-sided. Logistic regression analysis was performed to identify causative factors for palsy of the radial nerve. The site of fracture, the pattern, age and mechanism of injury were treated as independent variables. The values were expressed as the odds ratio (OR) with corresponding 95% confidence intervals (CIs) and P-values. The results were considered to be significant at $P < 0.05$.

In *Studies II–IV* the Mann-Whitney U-test was used for scale variables and ordinal variables in independent groups. Nominal variables were tested by the chi-square test or Fishers exact test. All tests were two-sided. The results were considered to be significant at $P < 0.05$. Trend values, $0.05 \geq P < 0.1$, are displayed; all other values are reported as not significant (N.S.).

ETHICS

All studies were conducted according to the Helsinki Declaration,[3] and the protocols were approved by the Local Ethics Committee. *Study I* was retrospective and all data were collected from the radiographic and medical records. *Studies II–IV* were retrospective in nature but with prospective assessment of functional outcome and HRQoL. These patients gave their informed consent to participate

STUDY I

The mean age was 63 (range 16–97) years. The mean age for females was 68 (16–97) years and for males 54 (16–90) years (*P*<0.001). The overall age distribution was bimodal with a minor peak in the third decade, consisting mainly of men sustaining high-energy injuries, and a major peak in the eight decade, mostly women with low-energy osteoporotic fractures (Figure 13). The overall incidence of humeral shaft fractures was 14.5 per 100 000 persons per year with an age-specific incidence gradually increasing from the fifth decade (Figure 14).

Figure 13
Age distribution (n=401)

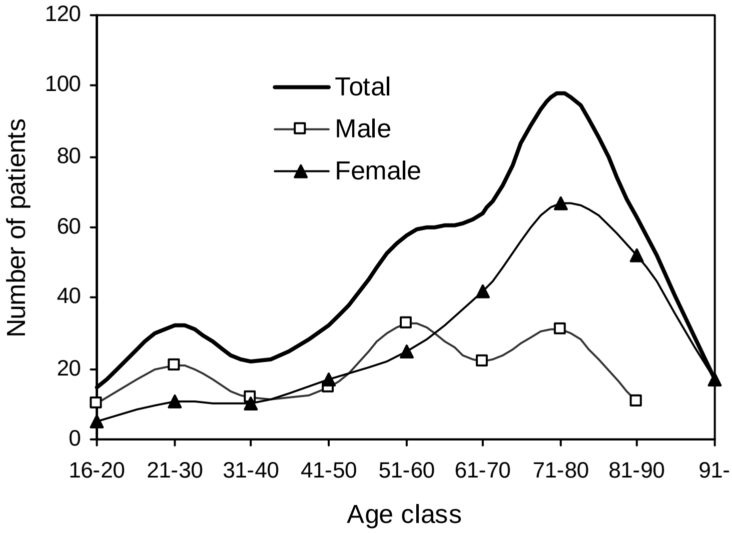


Figure 14
Age-specific incidence (n=401)

Most of the fractures were closed fractures in elderly patients sustained after simple falls. Type A (simple) fractures (61%) were by far the most common. Forty-three per cent of the fractures were located in the middle part of the humeral shaft, 41% in the proximal and 16% in the distal part. Type A1.2 was the most common fracture (18.8%) followed by Type A1.1 (11.4%) and Type A3.2 (9.7%) (Table 3).

Table 3
Classification of the 361 traumatic fractures in the OTA system, by number and percentage.

Pattern	**N** (%)	**Site**	**N** (%)	**Type**	**N** (%)
A	220 (61.0)	Proximal	75 (20.8)	A1.1	41 (11.4)
				A1.2	68 (18.8)
				A1.3	27 (7.5)
		Middle	114 (31.6)	A2.1	19 (5.3)
				A2.2	11 (3.0)
				A2.3	1 (0.3)
		Distal	31 (8.6)	A3.1	15 (4.2)
				A3.2	35 (9.7)
				A3.3	3 (0.8)
B	107 (29.6)	Proximal	45 (12.5)	B1.1	33 (9.1)
				B1.2	31 (8.6)
				B1.3	22 (6.1)
		Middle	38 (10.5)	B2.1	9 (2.5)
				B2.2	5 (1.4)
				B2.3	2 (0.6)
		Distal	24 (6.6)	B3.1	3 (0.8)
				B3.2	2 (0.6)
				B3.3	0 (0.0)
C	34 (9.4)	Proximal	27 (7.5)	C1.1	19 (5.3)
				C1.2	4 (1.1)
				C1.3	3 (0.8)
		Middle	4 (1.1)	C2.1	5 (1.4)
				C2.2	0 (0.0)
				C2.3	0 (0.0)
		Distal	3 (0.8)	C3.1	3 (0.8)
				C3.2	0 (0.0)
				C3.3	0 (0.0)
Totals	361 (100.0)		361 (100.0)		361 (100.0)

Low-energy trauma was the most common injury mechanism in all fracture types except for types A1.3, B1.3 and B3.1. Two per cent were open fractures and 2% of the fractures were associated with multiple trauma. There were 34 (8%) pathological fractures. Breast cancer was the most common in women and prostate cancer in men (Table 4).

Table 4
Data on the type of cancer in the 34 patients with pathological fractures of the humeral shaft, by number and percentage.

Origin of cancer	**Women**	**Men**	**Total** (%)
Breast	9 (40.9)	0 (0.0)	9 (26.4)
Myeloma	5 (22.7)	1 (8.3)	6 (17.7)
Kidney	2 (9.1)	3 (25.0)	5 (14.7)
Prostate	0 (0.0)	4 (33.3)	4 (11.8)
Lung	2 (9.1)	1 (8.3)	3 (8.8)
Miscellaneous	4 (18.2)	3 (25.0)	7 (20.6)
Totals	22 (64.7)	12 (35.3)	34 (100.0)

Thirty-four patients (8%) had acute radial nerve palsy and the logistic regression analysis showed that there was a significantly increased risk of radial nerve palsy with fractures of the middle and distal shaft (Table 5).

Table 5
Regression analysis of factors relating to palsy of the radial nerve.

Factor		**Univariable**		**Multivariable**	
		OR (95% CI)	***P***	**OR (95% CI)**	***P***
OTA class	Proximal	1 (reference)		1 (reference)	
	Middle	6.3 (1.8–21.7)	<0.005	7.2 (1.9–27.7)	**<0.005**
	Distal	12.5 (3.4–46.3)	<0.001	11.2 (2.7–46.3)	**<0.005**
OTA class	A	1 (reference)		1 (reference)	
	B	0.9 (0.4–2.0)	N.S.	0.8 (0.3–1.9)	N.S.
	C	0.9 (0.3–3.3)	N.S.	2.4 (0.6–10.4)	N.S.
Injury mechanism	Low-energy	1 (reference)		1 (reference)	
	High-energy	2.4 (1.1–5.1)	<0.05	1.5 (0.6–3.7)	N.S.
Age	> 50 years	1 (reference)		1 (reference)	
	≤ 50 years	2.8 (1.3–5.7)	< 0.01	1.6 (0.7–3.9)	N.S.

STUDY II

BACKGROUND DATA

The mean age of these 78 primarily non-operatively treated patients was 58 (range 16–91) years. Male patients were significantly younger than female patients, mean age, 46 and 64 years, respectively (*P*<0.05). Simple fall was the most common injury mechanism. Fracture type A (simple) was the most common fracture type and the fractures were located most often in the proximal or middle third of the shaft. There was a trend to more frequent low-energy trauma mechanisms in female patients (*P*=0.05). Two patients (3%) had open fractures and five patients (6%) had acute radial nerve palsy.

SURGICAL OUTCOME

Ninety per cent of the fractures healed on non-operative treatment, while 10% (8 patients) required an additional operative procedure because of non-union. These patients were treated operatively with a mean of 8.7 (range 1.8–15.5) months after the fracture; six patients with plating and additional bone grafting and two with intramedullary nailing. Seven of eight (88%) non-unions healed. The non-union in the patient treated with an antegrade intramedullary nail failed to heal, and the patient declined further surgery. There was a trend to an increased number of non-unions in patients with OTA type A fractures (*P*= 0.08).

FUNCTIONAL OUTCOME AND HRQoL

Forty-nine per cent of the patients with a healed fracture after non-operative treatment but none of the patients with a healed non-union after operative treatment reported full recovery at the follow-up (*P*<0.05) (Table 6). The SMFA scores were generally better in patients with a primarily healed fracture compared to those with a healed non-union after surgical intervention. The SF-36 scores, except for bodily pain (BP), were generally worse (lower) compared to the Swedish reference population.[85]

Table 6
Functional outcomes for the patients with a healed fracture after non-operative treatment (n=43) and for the patients with a healed non-union after surgical treatment (n=6).

	All patients (n=49)	**Non-operatively treated** (n=43)	**Surgically treated non-union** (n=6)	***P***
n (%)				
Fully recovered	21 (43)	21 (49)	0 (0)	**<0.05**
Mean (SD)				
SMFA Indexes				
Dysfunction Index	22.0 (20.9)	21.0 (20.0)	30.3 (27.9)	N.S.
Bother Index	20.5 (20.2)	18.8 (18.9)	33.8 (27.0)	N.S.
SMFA Categories				
Arm/hand function	13.7 (19.7)	12.4 (19.1)	23.1 (23.7)	N.S.
Daily activities	24.9 (27.0)	24.2 (26.1)	30.0 (36.7)	N.S.
Emotional status	32.9 (20.6)	31.4 (20.6)	44.3 (19.0)	N.S.
Mobility	17.8 (22.4)	16.7 (20.7)	26.1 (34.6)	N.S.

STUDY III

BACKGROUND DATA

The mean age of these 33 patients with primary radial nerve palsy was 56 (range 16–94) years. Most fractures were sustained after a low-energy trauma. Fracture type A (simple) according to the OTA classification was the most common fracture pattern and the fractures were located most often in the middle and distal part of the shaft. Women were significantly more often treated non-operatively and there was a trend towards more frequent operative intervention in fractures located in the distal part of the shaft (Table 7). All fractures were closed and evenly distributed with regard to side. The proportion of patients with primary radial nerve palsy undergoing surgery, 15 out of 33 (45%), was significantly higher compared to patients without palsy, 61 out of 328 (19%) ($P < 0.001$).

Table 7
Background for all patients (n=33) and in relation to the primary treatment modality, i.e. non-operative (n=18) or operative (n=15).

	All patients (n=33)	**Non-operative** (n=18)	**Operative** (n=15)	***P***
Mean (SD)				
Age, years	55.8 (24.3)	60.7 (25.1)	49.9 (22.6)	N.S.
n (%)				
Gender				
Female	19 (58)	15 (83)	4 (27)	**<0.005**
Male	14 (42)	3 (17)	11 (73)	
Injury type				
High-energy	10 (30)	5 (28)	5 (33)	N.S.
Low-energy	23 (70)	13 (72)	10 (67)	
Fx type				
12A	21 (64)	9 (50)	12 (80)	N.S.
12B	9 (27)	6 (33)	3 (20)	
12C	3 (9)	3 (17)	0 (0)	
Fx localization				
Proximal	3 (9)	3 (17)	0 (0)	0.082
Middle	18 (55)	11 (61)	7 (47)	
Distal	12 (36)	4 (22)	8 (53)	

RECOVERY OF RADIAL PALSY AND FRACTURE HEALING

Eighteen of the 33 patients (55%) were treated primarily *non-operatively*. Sixteen of these 18 patients (89%) had healed fractures while two patients developed a non-union. Both of these patients were treated successfully with internal fixation and bone grafting. Both patients had recovered their radial nerve function before the surgical intervention. Sixteen patients (89%) displayed a complete clinical recovery of their radial nerve palsy, while two patients (11%) had minor sequelae, i.e. persisting hyperaesthesia.

Fifteen of the 33 patients (45%) were treated primarily *operatively* and their fractures healed after the index procedure. In 11 of the 15 patients (73%) treated primarily operatively, nerve function recovered completely while two patients (13%) had minor sequelae, viz. persisting hyperaesthesia, and two patients (13%) had major sequelae, viz. one partial nerve palsy and one total radial nerve palsy.

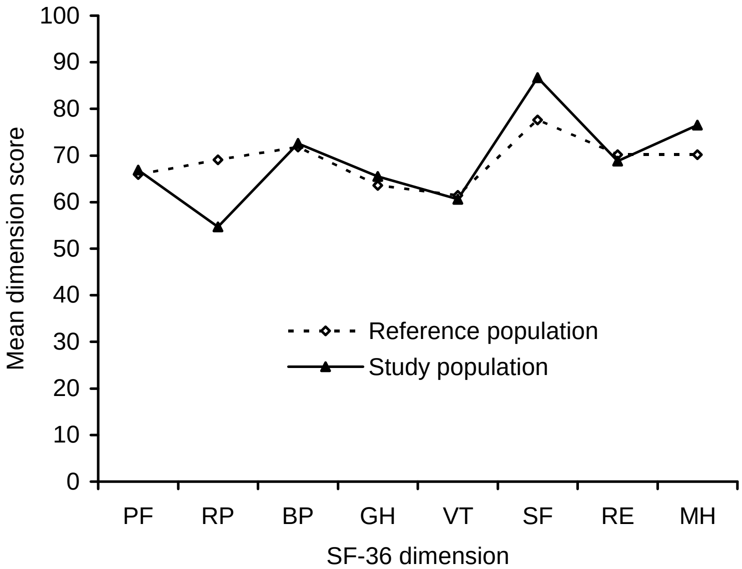
FUNCTIONAL OUTCOME AND HRQoL

There were no significant differences in baseline data on comparing the eight patients who were treated initially non-operatively with the eight patients treated primarily operatively except that females were treated non-operatively more often than males ($P < 0.05$).

The ROM of the injured shoulder, elbow, and wrist was generally impaired compared to the uninjured side, this being somewhat more pronounced in the wrist. The muscular strength of the injured shoulder and hand was also slightly impaired, and significantly more so in the shoulders of the operatively treated patients.

The long-term SMFA scores for our patients were almost identical to those of the reference population of patients with healed fractures without associated radial nerve palsies in *Study II*. The SMFA Dysfunction Index was 21.2 and 20.8, and the SMFA Bother Index was 18.2 and 18.2, respectively. The DASH score was 11.1. The SF-36 dimension scores were also generally comparable to those of the reference population (Figure 15). There were no significant differences in the SMFA, DASH or SF-36 scores on comparing operatively to non-operatively treated patients.

Figure 15
SF-36 dimension scores for patients with primary radial palsy (n=16) compared to a reference population of patients from *Study II* with a healed non-operatively treated humeral shaft fracture without associated radial nerve injury.



STUDY IV

BACKGROUND DATA

The mean age of the 27 patients with a Holstein-Lewis fracture was 51 (range 16–90) years. There was a trend towards patients with a Holstein-Lewis fracture being younger than those with other fracture types. All fractures were closed and none of the patients were involved in multiple trauma even though patients with a Holstein-Lewis fracture had sustained their fracture significantly more often following a high-energy trauma ($P<0.05$). The Holstein-Lewis fracture was significantly more frequently associated with radial nerve palsy, i.e. in 6 out of 27 patients (22%) compared to 27 out of 334 patients (8%) with other fracture types ($P<0.05$) (Table 8).

Table 8
Background data for all patients with a Holstein-Lewis fracture (n=27) in relation to treatment modality, i.e. non-operative (n=20) or operative (n=7).

	All patients (n=27)	**Non-operative** (n=20)	**Operative** (n=7)	***P***
Mean (SD)				
Age, years	51.3 (27.7)	52.6 (28.6)	47.6 (26.6)	N.S.
n (%)				
Gender				
Female	18 (67)	15 (75)	3 (43)	N.S.
Male	9 (33)	5 (25)	4 (57)	
Injury type				
Low-energy	17 (63)	12 (60)	5 (71)	N.S.
High-energy	10 (37)	8 (40)	2 (29)	
Radial palsy				
yes	6 (22)	2 (10)	4 (57)	**<0.05**

RECOVERY OF RADIAL PALSY AND FRACTURE HEALING

Seven of the patients (26%) with a Holstein-Lewis fracture were *operatively* treated primarily. Patients with associated radial nerve palsy were significantly more often treated operatively ($P<0.05$), but with regard to other baseline data, there were no differences between those treated non-operatively and those treated operatively (Table 8). The fractures of six out of seven of the operatively treated patients (86%) healed after the primary surgical procedure, which was preformed at a mean of nine days (range 1–28) after the injury. One of the patients (14%) required revision surgery with renewed plate fixation after 30 days to achieve healing. Four of the operatively treated patients had primary radial nerve palsy. The nerve was explored and found to be macroscopically intact in all four patients, and the radial nerve injuries healed.

Twenty patients (74%) were treated *non-operatively*. All their fractures (100%) healed without any further intervention. Two of these non-operatively treated patients had primary radial nerve palsy, and both of these nerve injuries healed.

FUNCTIONAL OUTCOME

There were no significant differences between the non-operatively and operatively treated patients with a Holstein-Lewis fracture with regard to functional outcome. The SMFA Dysfunction Index was 7.6 and 9.7, respectively, and the SMFA Bother Index, 6.1 and 6.8, respectively. The ROM of the injured shoulder, elbow and wrist of the 16 patients available for physical examination was hardly affected and the muscular strength of the injured shoulder and hand was only slightly impaired compared to the uninjured side. The neurological examination was normal in all patients.

ADDITIONAL DATA

AVOIDABLE INJURIES IN CONNECTION WITH THE TREATMENT OF HUMERAL SHAFT FRACTURES

BACKGROUND

The possibility of receiving compensation for injury caused in connection with the provision of health and medical care in Sweden is regulated by the Act on Injury to Patients. Under this act, both public and private care providers are obliged to have a medical malpractice insurance policy that covers indemnity for injuries to patients. Indemnity for personal injury can, following review, be paid if the injury concerned could have been avoided, if it was caused by faulty medical equipment or by an incorrect diagnosis, if infection has been transmitted in the course of treatment, in the event of accidents in connection with medical care and in connection with the incorrect prescription of medicines. There is no entitlement to indemnity in cases where the treatment concerned simply does not lead to the desired result or where complications arise. If an injury is indemnifiable, indemnity may comprise payment for loss of income, additional costs, pain and suffering, disfigurement and disability and special inconvenience. Injuries related to orthopaedics account for 21% of all reported cases, corresponding to 23% of the total costs of the insurance (years 1997–2001).[2] The compulsory malpractice insurance for health care financed publicly by the Swedish counties is supplied by one insurance company, the County Councils' Mutual Insurance Company (Landstingens Ömsesidiga Försäkringsbolag, LÖF),[2] covering more than 95 per cent of all health care in Sweden.

PATIENTS AND METHODS

Data for all patients with humeral shaft fractures who had reported during the years 1998-2006 to the County Councils' Mutual Insurance Company, that they had suffered an injury in connection with the treatment of the fracture, were identified through the computerised files at Personskadereglering AB (PSR),[2] and a review of relevant documents was done. During this time period, a total of 66 patients reported injuries related to treatment of humeral shaft fractures. In 46 (69.6%) of the cases, the injury was considered to be avoidable, and the patient was compensated.

RESULTS

The mean age of the patients was 55 years (range 20–80 years). The females (n=41, mean age 62 years, SD=17.8) were significantly older than the males (n=25, mean age 43 years, SD=21.2), (P=0.000). All the patient-reported treatment-related injuries are summarized in Table 9. There were no differences regarding gender or age between the patients who were judged to have an avoidable (n=46) and those to have a non-avoidable injury (n=20).

Fracture-treatment-related avoidable injuries (n=15) were usually caused by a delayed treatment of a non-union or due to non-optimal use of the operative method chosen, or both. An avoidable and compensated radial nerve injury (n=15) occurred in 9 cases when the surgery was performed acutely (within 6 weeks) and in 6 cases during the operative treatment of a non-union. In 9 of these cases the method chosen was a plate fixation (6 acute and 3 non-unions) and in 6 cases an intramedullary nail was used (3 acute and 3 non-unions).

Of all avoidable and thereby compensated 46 cases only five (10.9%) were related to non-operative treatment (i.e. no surgery was performed during the follow-up period).

Table 9
Summary of the treatment related injuries reported to PSR during the years 1998-2006.

	All injuries (n=66)	**Avoidable injury** (n=46)	**Unavoidable injury** (n=20)
n (%)			
Fracture-treatment-related injury	16 (24.2)	15 (32.6)	1 (5.0)
Radial nerve injury	18 (27.3)	15 (32.6)	3 (15.0)
Non-union	9 (13.6)	1 (2.2)	8 (40.0)
Infection	4 (6.1)	3 (6.5)	1 (5.0)
Malunion	6 (9.1)	3 (6.5)	3 (15.0)
Other	13 (19.7)	9 (19.6)	4 (20.0)
Total	66 (100.0)	46 (100.0)	20 (100.0)

The injuries reported by patients to the County Councils' Mutual Insurance Company do not show all possible complications following the treatment of humeral shaft fractures, but they give a hint about the most serious complications after surgical treatment. There are two major areas that are liable for indemnity: poor treatment of the fracture and injuries to the radial nerve.

A variety of surgical techniques have been described for the treatment of humeral shaft fractures that are either acute or secondary due to non-union. Any treatment given without providing sufficient stability and a likelihood of healing is regarded as indemnifiable, that is, in proper hands, the complication would have been avoidable and the patient is therefore reimbursed.

Injuries to the radial nerve are likewise regarded as avoidable provided that the surgeon has used an adequate surgical technique, i.e. paying attention to and protecting the nerve during the surgical procedure.

GENERAL DISCUSSION

The papers of this thesis are all based on data from 397 consecutive patients with 401 humeral shaft fractures belonging to a defined population during a defined period of time and thereby satisfying the basic criteria for epidemiological research. There is only one previous study that satisfies these criteria describing the epidemiology of 249 humeral shaft fractures in Edinburgh during 1989–92.[88]

Our overall aim has been to provide updated epidemiological data (*Study I),* but also to make use of this population and the possibilities given by the Swedish personal identification number system to identify these patients and ask them to return for a long-term follow-up including an evaluation of function and HRQoL.

In *Study II* we presented the long-term functional outcome assessed by validated instruments, i.e. the SMFA and the HRQoL according to SF-36 for patients with isolated humeral shaft fractures after closed functional treatment.

In *Study III* we reported on the recovery of radial nerve function in patients with closed humeral shaft fractures and associated primary radial nerve palsy in relation to the treatment modality, i.e. operative or nonoperative treatment. Moreover, the long-term functional outcome according to the SMFA and DASH and the HRQoL according to SF-36 for patients with this particular injury was reported.

Finally, in *Study IV* we described the epidemiology of the relatively rare Holstein-Lewis humeral shaft fracture, its association with radial nerve palsy and the outcome regarding recovery from the radial nerve palsy and fracture healing. Furthermore, the long-term functional outcome according to the SMFA for patients with this particular injury was presented.

EPIDEMIOLOGY (*Study I*)

The epidemiological aspects of humeral shaft fractures have attracted rather little attention in the past. During the last 30 years there have been only a few pertinent studies covering this topic,[11,45,55,72,88,95] most of them focusing on treatment outcome and including selected patient cohorts, most frequently patients admitted to trauma centres. Our results regarding age distribution, gender, injury mechanism and fracture pattern were in conformity with the findings of the single previous comparable study by Tytherleigh-Strong *et al*.[88] Both studies showed a bimodal age distribution with a minor peak in the third decade consisting of mainly men sustaining a high-energy trauma and a second major peak in the eighth decade mainly involving women with osteoporotic fractures as a result of simple falls. Other studies[11,45,55,77,95] have indicated a shift of the age distribution towards a younger population, most likely due to the fact that these studies included a higher proportion of high-energy trauma patients referred to designated trauma centres. Another reason for the different results may be that the epidemiology of humeral shaft fractures reflects the overall incidence of high-energy trauma in the society, and our study and the study by Tytherleigh-Strong[88] reflect the overall low incidence of high-energy trauma in Sweden and Great Britain, respectively, compared to the relatively higher incidence in the USA.[55,77,95] Furthermore, our finding of a low incidence of open fractures and patients with multiple injuries is a consequence of the low incidence of high-energy trauma in our society.

Our reported overall incidence at all ages was lower than that reported by Tytherleigh-Strong,[88] although both show the same age pattern with a gradually increasing incidence from the fifth decade reflecting the influence of osteoporosis on the risk of sustaining a humeral shaft fracture. On looking at the absolute number of patients in each age group, the vast majority of them, more than 75%, were found to be over 50 years of age. This information should be considered before planning for more frequent surgical interventions in these types of fracture. Although the majority of the fractures are simple type A, there may be a fixation problem owing to the high percentage of patients with varying degrees of osteoporosis.

The majority of our patients sustained their fracture in the middle (43%) or proximal (41%) part of the shaft. This differs somewhat from what was reported by Tytherleigh-Strong *et al*.,[88] who reported 64% mid-shaft fractures and 25% proximal fractures. Different methods of classifying proximal shaft fractures may be the explanation for this finding. However, their finding of a lower incidence of distal fractures was in agreement with our results.

Slightly more than 8% of our patients had associated radial nerve palsy, which is in conformity with the findings of studies by Bleeker and Koch.[11,45] Others[55,77,84] have reported an incidence of radial nerve palsy in the range of 11–18%, probably owing to a higher degree of selection of patients with high-energy and penetrating traumas. Most radial nerve palsies are a result of fractures in the middle part of the humeral shaft: 59% in our study, which is well in accord with other studies ranging from 64% to 94%.[11,45,84] However, the risk for having radial nerve palsy seems to be highest in the less common fracture of the distal part of the shaft where the nerve is trapped in the lateral intramuscular septa and therefore extra vulnerable.[40]

Our finding of 8% pathological fractures is comparable to the 6% reported by Tytherleigh-Strong *et al*.[88] Not surprisingly, the most frequent cause of a pathological fracture was breast cancer in women and prostate cancer in men. These patients pose significant challenges to the treating surgeon due to their co-morbidities and the fact that pathological fractures almost never heal regardless of the treatment modality. However, fracture fixation is mandatory in most of these patients in order to reduce pain and improve the quality of life during their remaining life-time.[92]

OUTCOME AFTER CLOSED FUNCTIONAL TREATMENT (*Study II*)

Our finding of a 90% overall union rate after closed functional treatment of humeral shaft fractures is equal to that reported by Koch *et al*.[45] and better than the 77% reported by Toivanen *et al*.,[87] but not comparable to the 98% union rate reported by Sarmiento *et al*.[77] One explanation for the difference may be the high percentage of patients lost to follow-up in the latter study, 33%, in comparison with our study, 0%, possibly resulting in a positive patient selection. Another explanation may be that our patients did not adhere sufficiently to the recommended treatment regimen. A properly performed fracture brace treatment of a humeral shaft fracture, as recommended by Sarmiento,[77] includes daily adjustment and tightening of the brace. Initially, the patients use a collar-and-cuff sling but are encouraged to perform active and passive exercises daily of the elbow, wrist and fingers. They are also allowed passive pendulum exercises of the shoulder but no active elevation or abduction of the shoulder until the fracture is clinically stable. The brace is removed upon confirmation of clinical and radiographic union, which is reported to occur at a mean of 11.5 weeks.[77] Closed functional treatment, i.e. fracture brace treatment, of a humeral shaft fracture is an active treatment modality and the regimen, as described by Sarmiento and co-workers, needs to be thoroughly supervised if the treatment is to be successful.

Nearly 90% of our non-unions healed after revision surgery. In the vast majority of the patients, we performed plate fixation with an adjunct bone transplant, and with this method we achieved fracture healing in all cases. This good outcome is in conformity with the literature in which plate fixation is the most frequently recommended method for humeral non-unions,[54,59] and also for selected indications in primary cases.[57,59] The inferior outcome for intramedullary nails in humeral shaft fractures as well as in non-unions is well documented and the role for nailing in the humerus remains to be defined.[1,10,23] The best indication for nailing is probably an impending or established pathological fracture of the humeral shaft.[59]

To the best of our knowledge, there are no previous self-reported outcomes for humeral shaft fractures after closed functional treatment. Sarmiento *et al*.[77] reported full shoulder motion in approximately 60% and full elbow motion in 75% of the patients, which figures are similar to the data on shoulder and elbow motion reported by Koch *et al*.[45] Based on pain and shoulder/elbow motion, the authors in the latter study classified the results in 50% of their patients as excellent. This is in conformity with our result with nearly 50% of the patients reporting to be fully recovered. The SMFA and SF-36 data are more difficult to interpret since there are no comparable data in the literature for patients with humeral fractures treated non-operatively or operatively. The overall impression is that the patients are reasonably well recovered after a successful fracture brace treatment. The final outcome for patients with a healed non-union after revision surgery seems to be worse, which is not surprising considering the prolonged period of brace treatment before the surgical procedure.

The incidence of radial nerve palsy in our patient cohort was 9 out of 92 (10%) if we include all patients from the two-year period with an acute isolated non-pathological humeral shaft fracture. But since the radial nerve palsy was an indication for primary operative intervention for some of the treating surgeons, we were only able to follow those treated non-operatively. The recovery of nerve function was good in all five of these patients: three were fully recovered clinically and two had minor sensory disturbances but normal motor function. These data are at a par with the 11% of radial nerve palsy in closed humeral shaft fractures reported by Sarmiento *et al*.[77] The incidence of radial nerve palsy in open fractures, mostly gunshot injuries, in the same study was 10%. Nearly all of them, regardless of whether it was an open or a closed injury, recovered nerve function after conservative fracture treatment.

The finding of female patients being older and more often sustaining their fracture after a low-energy trauma is in agreement with the epidemiological data presented by Tytherleigh-Strong *et al*.,[88] but compared to their results, the age distribution of men in our study displayed an apparent bimodal distribution with sharp peaks in both in the third and eighth decade.

There was a trend toward more frequent non-unions in simple fracture patterns, i.e. type A according to the OTA classification, a finding also previously reported by Koch *et al*.[45] In conformity with our results, approximately 50% of the non-unions in their study were in simple mid-shaft fractures. Our incidence of non-unions after type A fractures was almost equal in proximal and mid-shaft fractures, approximately 20%. This increased incidence of non-unions in the proximal shaft has previously been reported by Toivanen and co-workers.[87] The finding of more frequent non-unions in type A fractures was in contrast to type B and C fractures, where non-union was extremely rare regardless of localization. The comparatively high rate of non-unions in simple fractures in this and previous studies,[45] the reported relatively long period of time in a brace until union,[77] the fact that approximately 50% of patients are not fully recovered after non-operative treatment and the fact that simple fractures are suitable for plate fixation raise the question of whether an alternative method, i.e. plate fixation, could improve the outcome. Considering the major improvements in plate fixation in recent years, e.g. angular stable screws, and the good outcome after plate fixation in patients with selected indications,[10,14,57] it may be time for a randomized controlled trial comparing closed functional treatment and plate fixation in closed simple (type A) humeral shaft fractures.

RADIAL NERVE PALSY (*Study III*)

The overall radial nerve recovery rates were comparable to those of previous studies.[4,11,19,32,48,50,66,68,70,80-82,84] Moreover, as in the systematic review by Shao *et al.*,[81] we could not find any advantage with early surgical intervention. In contrast, the only two patients (6%) in our study with major sequelae after their radial nerve injury were both in the operatively treated group. In neither of these two patients was the radial nerve explored during surgery, thus indicating an undiagnosed laceration of the nerve or, even worse, the possibility of an iatrogenic nerve injury. If, for any reason, the closed shaft fracture in a patient with radial nerve palsy requires early internal fixation, e.g. multiple trauma, segmental or bilateral fractures, combination with a forearm fracture ("floating elbow") and in some fractures caused by high-energy trauma,[59] there are several good reasons to explore the nerve simultaneously. Although most studies indicate a high incidence of spontaneous nerve recovery, there are occasional patients with lacerated nerves and, in these cases, the primary operation is probably the optimal occasion to assess the status of the nerve and, in closed fractures, to perform the nerve reconstruction. Moreover, in patients with non-recovery of nerve function after the primary internal fixation, a later secondary exploration is a more technically demanding procedure where the nerve could be embedded in callus.[59] Finally, a primary surgical intervention including exploration of the nerve is only marginally more technically demanding than an intervention without exploration of the nerve and could possibly also reduce the risk of an iatrogenic nerve injury. The management of the radial nerve palsy in patients with open fractures where the risk of a lacerated nerve is significantly higher is less controversial. In open fractures an exploration of the nerve is recommended at the time of fracture fixation, i.e. nearly always acutely.[24,70]

Our results for ROM in the shoulder, elbow and wrist and the muscular strength of the injured arm were generally good, showing only minor impairment, which was most pronounced in the shoulder and handgrip strength. These results are in conformity with those of Sarmiento *et al.*,[77] who reported less than 10 degrees of loss of motion in the shoulder and elbow in almost 90% of the patients after closed functional treatment. On comparing the primarily non-operatively treated patients with those treated operatively, we did not find any significant differences, except that shoulder strength was significantly reduced in the operatively treated group. In a meta-analysis comparing compression plating to intramedullary nailing of humeral shaft fractures in 155 patients, Bhandari *et al*.[10]concluded that plate fixation may reduce the risk of reoperation and shoulder impingement. However, the decrease in shoulder strength in our study group was not more pronounced in the patients treated with an antegrade nail than in those treated with a plate. Considering the limited number of patients, our results may very well reflect insufficient statistical power.

The SMFA and SF-36 results for our patients with primary nerve palsy were almost identical to the results of our reference population in *Study II* of patients with healed humeral shaft fractures without associated radial nerve palsies. The DASH score was excellent with a mean of 11.1 and no significant differences between operatively and non-operatively treated patients. These findings suggest that the outcome after a closed humeral shaft fracture is more dependent on the healing and treatment of the fracture itself than on the primary nerve palsy.

The finding of a significantly higher rate of primary operations in patients with radial nerve palsies compared to those without palsy, 45% and 19%, respectively, indicates that the primary radial nerve palsy was a contributing factor in the decision making for a number of the orthopaedic surgeons at the participating hospitals. Furthermore, the trend towards more frequent operative intervention in distal fractures could indicate that specific fracture patterns, e.g. a Holstein-Lewis fracture, was an indication as well in selected cases. However, the results of our study and previous ones contradict the opinion that primary radial nerve palsy *per se* is an indication for early operative intervention in patients with closed humeral shaft fractures.[21,70,81]

THE HOLSTEIN-LEWIS FRACTURE (*Study IV*)

Our results confirm the increased risk of sustaining an associated primary radial nerve palsy in this particular fracture pattern as previously reported.[40,81] Despite the previous recommendations that open reduction and internal fixation should be regarded as the treatment of choice for this type of injury,[40] the majority of our patients were treated non-operatively although the subgroup of patients with associated radial nerve palsy were operated on more often. Furthermore, in contrast to the report by Holstein and Lewis,[40] none of our patients developed secondary palsy during the non-operative treatment.

The fractures of all non-operatively treated patients healed, and they recovered their radial nerve function. The outcome regarding radial nerve recovery was equally uneventful in the operatively treated group, while one patient developed non-union which healed after revision surgery.

The long-term functional outcome according to the SMFA was generally good, and the patients with a Holstein-Lewis fracture had better (lower) SMFA scores than a reference population in *Study II* of patients with healed humeral shaft fractures without associated radial nerve palsies regarding both the Dysfunction Index (8.1 and 20.8, respectively) and the Bother Index (6.3 and 18.2, respectively). The overall good SMFA results were reflected in only limited restrictions in the ROM of the injured shoulder, elbow and wrist, and the muscular strength of the injured shoulder and hand. Furthermore, there were no differences in these aspects on comparing the non-operatively treated patients with those treated operatively.

STRENGTHS AND LIMITATIONS

A major strength of *Study I* and *Studies II–IV* is that our patients belong to a large defined population admitted during a defined period of time. The Swedish personal identification number system allowed us to identify virtually all patients with humeral shaft fractures in the Stockholm area during this period of time. The fact that the study design was retrospective, with several hospitals included, seemed to be of minor importance as our data were based on the first hospital visit, and patient records and radiographs were available for all these patients. The radiographs from the smaller outpatient clinics were not screened for humeral shaft fractures, but this should not influence the interpretation of our results since patients with humeral shaft fractures in Sweden are referred to major hospitals. Moreover, the clinical follow-up rate regarding fracture healing and radial nerve recovery in *Studies II–IV* was 100%.

The major limitations of *Studies II–IV* are the retrospective design. In *Study II* this resulted in 14 out of 92 eligible primary patients being treated surgically according to the treating surgeon's preference. Secondly, the follow-up rate for the assessment of functional outcome (SMFA) and HRQoL (SF-36) was only 64% and the patients available at the final follow-up were older and had sustained their fracture more often after a low-energy trauma, which could limit the strength of the conclusion regarding functional outcome and HRQoL.

In *Study III*, the ageing of some of our patients in combination with a long follow-up period, resulting in a number of patients being lost to follow-up because of secondary morbidity and/or mortality, contributed to limited follow-up information on the functional outcome and HRQoL, which was available for only 48% of the patients. However, the baseline data for patients attending the follow-up did not differ significantly from those for the patients who did not.

In *Study IV* the fact that only 67% of the patients were available for the follow-up of the long-term functional outcome is a limitation. However, the long follow-up period did result in 22% of the patients having deceased.

Despite these limitations, we believe that our results are amenable to generalization in the defined population, i.e. adult patients with closed humeral shaft fractures after blunt trauma.

CONCLUSIONS

STUDY I

The results of this study provide updated data on the epidemiology of humeral shaft fractures in a population with a limited amount of high-energy and penetrating trauma, a situation that prevails in most European countries.
The incidence of humeral shaft fractures was 14.5 per 100 000 persons per year with a gradually increasing age-specific incidence from the fifth decade in both genders and reaching an incidence of almost 60 per 100 000 persons per year in the ninth decade. The majority of the fractures were closed fractures in elderly patients sustained after simple falls. The age distribution among females was characterized by a single high peak in the eight decade, while the age distribution in men was more evenly distributed. Type A (simple) fractures were by far the most common and the majority of the fractures were located in the middle and proximal part of the humeral shaft. Only 2% of the fractures were open and 8.5 % were pathological. The incidence of radial nerve palsy was 8.5% and there was a significantly increased risk of radial nerve palsy with fractures of the middle or distal shaft.

STUDY II

This study confirmed the high overall rate of union of humeral shaft fractures and an acceptable functional outcome after successful fracture-brace treatment. However, in Type a (simple) fractures, the non-union rate seemed to be higher, and patients with healed non-unions after revision surgery had worse functional outcomes.

STUDY III

This study confirmed the high spontaneous recovery rate of primary radial nerve palsies in patients with closed humeral shaft fractures, regardless of treatment modality. Primary radial nerve palsy should not be regarded as an isolated indication for primary surgical intervention.

STUDY IV

This study showed that the Holstein-Lewis humeral shaft fracture was associated with a significantly increased risk of primary radial nerve palsy compared to other fracture types. The overall outcome regarding radial nerve recovery, fracture healing and function was excellent regardless of the primary treatment modality, i.e. operative or non-operative treatment. The indication for primary operative intervention in this specific fracture type appeared to be relative.

OVERALL CONCLUSIONS

Our studies provide recent epidemiological data on humeral shaft fractures in a population with a limited amount of high-energy and penetrating trauma, probably reflecting a situation that prevails in most European countries. These data can be used to facilitate the planning of treatment for patients with this particular fracture.

The treatment of choice for most closed humeral shaft fractures is still non-operative with an acceptable functional outcome and HRQoL. However, simple (type A) fractures - especially in the proximal and middle part of the shaft - seem to have a higher non-union rate, and patients with a healed non-union after surgery seem to have worse functional outcome.

The indication for operative treatment of closed humeral shaft fractures with concomitant acute radial nerve palsy appears to be only relative even in the presence of a Holstein-Lewis fracture. The outcome appears to be mainly correlated with the fracture itself, with the radial nerve palsy playing only a minor role. If, for any reason, an acute closed humeral shaft fracture with radial nerve palsy requires internal fixation, we believe that the radial nerve should be explored simultaneously in order to be able to assess the status of the nerve and, if needed, perform an acute nerve reconstruction.

IMPLICATIONS FOR FUTURE RESEARCH

The golden standard for the treatment of closed, isolated humeral shaft fractures is non-operative. However, recent technical advances of internal fixation and increasing patient expectations may lead to an increased interest in internal fixation. This thesis (*Study II)* and previous studies[45] have shown a higher non-union rate in selected fracture patterns, i.e. type A fractures. Although the functional outcome is generally good, patients do have some limitations in ROM of the shoulder and elbow, reduced strength and limitations in function according to the SMFA. Moreover, patients with a non-union after primary non-operative treatment that has healed after surgical intervention have an even worse outcome (*Study II*).

In summary, there seem to be good reasons to conduct a randomised controlled trial to compare internal fixation with non-operative treatment of humeral shaft fractures, especially in patients with type A fractures. Current data[10,14] favour plate fixation in comparison with intramedullary nailing. However, plate fixation as well as intramedullary nailing of the humerus is demanding surgical procedures requiring experience and considerable skill. This assumption is supported by data from the Act on Injury to Patients reporting a number of iatrogenic radial nerve injuries (*Additional Data*). One explanation for why such a trial has not yet been performed is the considerable number of patients necessary to achieve an acceptable statistical power, necessitating a multi-centre approach.

ABSTRACT IN SWEDISH

Frakturer på överarmsskaftet svarar för 1-3 % av alla frakturer och cirka 20 % av alla frakturer på överarmen. Standardmetoden för behandling av denna skada är ickeoperativ där patienten erhåller en plastskena runt överarmen och behåller denna tills frakturen är kliniskt stabil. Studier har visat att denna behandlingsmetod leder till hög frakturläkningsfrekvens med goda funktionella resultat. Nervus radialis är den perifera nerv som oftast skadas i samband med rörbensfrakturer på överarmen. Den s.k. Holstein-Lewis frakturen, en enkel spiralfraktur i den nedersta tredjedelen av överarmsskaftet, har man historiskt ansett att man bör behandla operativt pga. dess starka association till skada på nervus radialis. Det finns dock endast ett fåtal moderna studier som beskriver långtidsresultat efter ickeoperativt behandlade patienter med fraktur på överarmsskaftet, patienter med primär radialispares i samband med denna fraktur, samt patienter med Holstein-Lewis fraktur, avseende funktionellt utfall och hälsorelaterad livskvalitet.

I *Delstudie I* identifierades samtliga 397 patienter (401 frakturer) i Stockholm under åren 1998-99 med frakturer på överarmsskaftet. Studien fokuserade på epidemiologiska data i denna population där det förekom endast en begränsad andel högenergiskador och öppna frakturer. Resultaten ligger till grund för *Delstudierna II-IV* och kan användas för att underlätta resursfördelning samt att förbättra behandling av patienter med denna fraktur.

I *Delstudie II* undersöktes de 78 patienter ur *Delstudie I* med fraktur på överarmsskaftet som hade behandlats primärt ickeoperativt på Södersjukhuset. Data avseende frakturläkning inhämtades från journalhandlingar. Patienterna undersöktes prospektivt avseende funktionellt utfall och HRQoL. Studien bekräftade den tidigare rapporterade höga frakturläkningsfrekvensen och de acceptabla funktionella resultaten hos patienter med denna typ av fraktur. Enkla frakturer (Typ A) föreföll dock ha sämre läkningstendens, och patienter som opererades i ett senare skede på grund av utebliven läkning hade ett sämre funktionellt långtidsresultat.

Trettiotre av de 397 patienterna med fraktur på överarmsskaftet hade redan vid skadetillfället en radialispares och inkluderades i *Delstudie III*. Data avseende den primära behandlingen (operativ eller ickeoperativ) samt läkning av radialisnervskadan och frakturen hämtades ur journalhandlingar. Patienterna utvärderades prospektivt avseende funktionellt utfall och hälsorelaterad livskvalitet. Studien bekräftade den höga spontanläkningsförmågan av radialisnervskadan respektive frakturen hos patienter med slutna frakturer på överarmsskaftet, oavsett behandling. Primär radialispares bör därför inte utgöra enda grunden för kirurgisk intervention i samband med frakturer på överarmsskaftet.

Tjugosju av de 397 patienterna med fraktur på överarmsskaftet hade en Holstein-Lewis fraktur och ingick i *Delstudie IV*. Data angående behandlingsmetod samt läkning avseende radialisnervskadan och frakturen inhämtades ur journalhandlingar. Patienterna utvärderades prospektivt avseende funktionellt utfall. Studien visade att Holstein-Lewis frakturen var förknippad med en signifikant ökad risk för primär radialisnervskada jämfört med andra frakturer på överarmsskaftet. Resultaten avseende återhämtning av radialisnervskadan, frakturläkning och det funktionella resultatet var utmärkta, oavsett primär behandlingsmetod. Indikationen för primär kirurgisk intervention vid denna specifika frakturtyp föreföll att vara endast relativ.

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