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INTRAMEDULLARY NAILING OF HUMERAL SHAFT FRACTURES

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Abstract

Although nonoperative treatment is recognized as an effective treatment method for humeral shaft fractures, it is associated with an approximately 10% risk of nonunion and long-term impairments of the shoulder joint. There is a growing interest to treat even simple humeral shaft fractures operatively to avoid these problems. Intramedullary (IM) nailing has proven to be very effective in the treatment of femoral and tibial shaft fractures and the same method has been adopted for humeral shaft fractures. However, the results regarding union rate and shoulder joint function after antegrade insertion of an IM nail have been very controversial.

The purpose of this study was to investigate fracture union, shoulder joint function and symptoms after antegrade IM nailing of humeral shaft fractures, to assess safety and results of IM nailing in pathological fractures, to evaluate the efficacy of exchange nailing and Ilizarov's technique in the treatment of nonunion after IM nailing and to find out, by comparing shoulder joint symptoms and function after antegrade IM nailing and dynamic compression (DC) plate fixation, whether antegrade access to the medullary cavity is the main reason behind shoulder joint problems.

During the years 1987-1997, 126 humeral shaft fractures were operated upon in Oulu University Hospital using antegrade IM nailing. The nonunion rate was 22% and distraction of the fracture fragments was the most important risk factor associated with nonunion. The reoperation rate, for various reasons, was 25%. Shoulder joint pain and impairment of function was present in 37% of the patients. In the treatment of 18 pathological fractures IM nailing was a rapid and safe operation, associated with good pain relief.

Exchange nailing of 13 cases of nonunion after IM nailing resulted in a union rate of 47% and this method is not useful in the humerus in contrast to tibial and femoral fractures. Permanent nonunion leaves the patient with severe impairment of the shoulder joint and a loose nail may lead to severe osteolysis of cortical bone. In complicated nonunion with poor bone quality, Ilizarov's technique, although associated with a high rate of minor complications and reoperations, worked well.

When IM nailing was compared with DC plating it was found that there were no significant differences in shoulder pain, function scores, range-of-motion and strength. Antegrade insertion of the nail, if carried out properly, is probably not the main reason for shoulder joint impairment after IM nailing.

Antegrade IM nailing of humeral shaft fractures is associated with several problems, e.g. shoulder joint impairment and difficulties in reconstruction after nonunion, and indications for this method may be exceptional, such as comminuted and pathological fractures.

Keywords: humeral fractures, Ilizarov technique, Intramedullary fracture fixation, pathological fractures, shoulder joint, ununited fractures
To my family
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Abbreviations

AO Arbeitsgemeinschaft für Osteosynthesefragen
ASIF Association for the Study of Internal Fixation
ASES American Shoulder and Elbow Surgeons
DC Dynamic compression
ER External rotation
IM Intramedullary
IR Internal rotation
ORIF Open reduction and internal fixation
PMMA Polymethylmetacrylate
ROM Range-of-motion
List of original papers

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


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1 Introduction

Simple humeral shaft fractures can be treated nonoperatively, with good results in most cases (Watson-Jones 1955, Böhler 1965, Charnley 1974, Jupiter & van Deck 1998, Gregory 2001, Sarmiento et al. 2001). Although complications are infrequent, nonoperative treatment requires a long period of immobilization, which carries a risk of prolonged shoulder joint stiffness and may be inconvenient for the patient (Rommens et al. 1995, Ulrich 1996b). Furthermore, nonunion after conservative treatment of these fractures does occur in up to 10% of the cases and treatment of this condition can be very difficult (Healy 1987, Foulk & Szabo 1995, Jupiter & van Deck 1998). There is growing interest in treating even simple humeral shaft fractures by dynamic compression (DC) plate fixation or intramedullary (IM) nailing in order to avoid these problems and to allow earlier mobilization and rapid return to work (Heim et al. 1993, Rommens et al. 1995, Kelsch et al. 1997).

Although early attempts at IM nailing of lower extremity fractures were carried out in the beginning of the 20th century, the first IM nailing of the humerus were carried out by the Rush brothers in the 1930’s in the USA (Rush 1955, Street 1996). They used their small calibre nails with success, especially in proximal diaphyseal fractures (Rush 1955). At the same time Gerhard Küntscher together with engineer Ernst Pohl in Germany were developing IM nailing techniques using a single larger intramedullary nail (Küntscher 1958, Lindholm 1982, Street 1996). This technique was originally applied to femoral and tibial fractures but was soon adopted for humeral shaft fractures (Küntscher 1962, Street 1996). Küntscher nailing became popular in the Northern part of Finland very rapidly, because Gerhard Küntscher worked during war years 1943 and 1944 in a German military hospital based in Kemi (Lindholm 1982). The first humeral nailings in Finland were carried out at that time (Lindholm 1982). Although IM nailing was soon accepted as an effective method to treat humeral fractures and cases of nonunion, there was little scientific evidence to support this (Küntscher 1962, Lindholm 1979, Lindholm 1982, Riemer 1996, Sarmiento et al. 2001).

Small calibre nails and larger nails without locking do not offer rotational stability, and proximal migration causing impingement and shoulder joint problems were common (Ulrich 1996a). The stacked bundle nailing, method developed by Hackenthal did not solve these problems (Ulrich 1996a).
Dynamic compression plating of humeral shaft fractures, popularized by the AO group in the 1960’s, replaced IM nailing in many countries and gave promising clinical results (Müller et al. 1963, Müller et al. 1969). The need for anatomic reconstruction and the absolute rigidity of AO techniques, however, easily leads to extensive soft tissue dissection (Müller et al. 1969, Schatzker & Tile 1987). Iatrogenic radial nerve lesion is a common complication of DC plating in humeral shaft fractures (Hall & Pankovich 1987, Sarmiento et al. 2001). In comminuted fractures, or if the bone is osteoporotic, stable osteosynthesis may be difficult to achieve (Ulrich 1996a). The success of plating techniques in the humerus has only recently been tested in clinical trials, but the results have not been convincing in comparison with other operative techniques (Ulrich 1996a).

Although Küntscher originally described a locking nail with transverse screws it was not until the late 1970’s when Klemm and Schellmann and later Grosse and Kempf improved this technique (Lindholm 1982, Street 1996). Locking screws solved the problem of rotational instability and migration and expanded the indications of IM nailing to include metaphyseal areas of long bone fractures (Lindholm 1982, Street 1996). Together with improved fluoroscopy techniques these new implants made locking IM nailing very popular, being a minimally invasive method to treat long bone fractures (Street 1996).

Locking IM nailing of the humerus was popularized by Hartmut Seidel, from Germany, and this technique with expandable fins for distal locking was used from the late 1980’s even in simple humeral shaft fractures (Seidel 1989, Ulrich 1996a, Street 1996). Later, during the 1990’s, locking IM nails for the humerus with transverse locking screws at both ends of the nails were developed (Street 1996).

Despite technical improvements of humeral IM nails, results after Seidel’s initial good results regarding union rate and shoulder joint function have been and still are very controversial (Seidel 1989, Ulrich 1996a, Sarmiento et al. 2001). Published union rates range from very poor to excellent (Robinson et al. 1992, Kelsch et al. 1997). Antegrade access to the medullary canal through the rotator cuff tendons may cause shoulder joint pain and impairment of function (Farragos et al. 1999). The real nature and cause of this problem, however, is poorly known (Riemer 1996). The treatment of nonunion after IM nailing is another issue which is poorly defined. Methods that are effectively applied to the femur and tibia may not work in the humerus (Farragos et al. 1999). Long-lasting nonunion with a loose IM nail may lead to complex nonunion with compromised bone quality, making traditional treatment methods very difficult or even impossible (Farragos et al. 1999). These problems, although being very difficult to treat, have received little attention in the literature. The purpose of this study was to address these controversial issues associated with IM nailing of humeral shaft fractures.
2 Review of the literature

2.1 Surgical anatomy of the humerus

The humerus is divided into three parts as regards surgical anatomy; upper part, diaphysis and inferior part. The diaphysis or shaft (Fig. 1) can be defined as that part of the humerus situated between the superior margin of pectoralis major tendon insertion and 2 cm above the olecranon fossa (Mast et al. 1975, Varley 1995). Tytherleigh-Strong et al. (1998) defined the supracondylar ridges as the lower border of the humeral shaft. Müller et al. (1990) defined the humeral shaft by defining first the extent of the proximal and distal segments of the bone. The proximal and distal segments of the humerus are each defined by a square whose sides are the same length as the widest part of the epiphysis (Fig. 1). The diaphyseal segment is between the proximal and distal segments. These different definitions suggest that there is some overlap between diaphyseal and upper or inferior part fractures of the humerus.

The rotator cuff tendons are inserted on the major and minor tuberosities (Gregory 2001). The supraspinatus tendon crosses the humeral head superiorly and is inserted on the superior aspect of the greater tuberosity (Gregory 2001). To access the medullary cavity via the antegrade route, the supraspinatus tendon usually has to be incised, which is considered to cause shoulder joint problems (Riemer 1996, Gregory 2001). The humerus is covered by a thick muscular layer (Fig. 1) in two compartments; the anterior compartment contains the brachialis, coracobrachialis and biceps muscles, and the triceps muscle dominates posterior compartment (Gregory 2001).

Humeral diaphyseal bone is supplied primarily by numerous nutrient arteries and a thick extraosseus soft-tissue sleeve provides a source of periosteal vessels that are concentrated around fascial attachments (Cole 1996). The direction of normal blood supply in diaphyseal bone is centrifugal, flowing from the medulla to the periosteum (Cole 1996).

The radial nerve crosses the lateral humerus in the distal third close to the bone and pierces the tight intermuscular septum, which makes it vulnerable to injury (Holstein & Lewis 1963, Gregory 2001).
2.2 Epidemiology and classification of humeral shaft fractures

Approximately 5–10% of all long bone fractures occur in the humerus (Rose et al. 1982). Humeral diaphyseal fractures account for about 20% of all humeral fractures (Rose et al. 1982). Mast et al. (1975), in their report on 240 humeral shaft fractures, found that 60% of the fractures occurred in the under 30 years age group. Gunshot wounds caused 17% of the fractures, reflecting a violent environment. Rose et al. (1982) found a similar age distribution in their study of 116 humeral shaft fractures and they reported an incidence of 20/100 000 patients/year. Most epidemiological data on humeral shaft fractures come from trauma centres, where usually a highly selected population is treated (Mast et al. 1975, Rose et al. 1982).

Tytherleigh-Strong et al. (1998) published the results of an epidemiological study on 249 consecutive humeral shaft fractures during a three-year period in Edinburgh, Scotland. The trauma centre serves a population of 600 000 and is responsible for the inpatient and outpatient care of injuries and the study gives epidemiological data in an unselected population. The incidence was approximately 14/100 000/year and 60% of the fractures occurred after a simple fall from standing position. The mean age of the patients was 55 years and 55% of the patients were women. Fractures occurring in patients over
50 years accounted for 60% of the total. There was a bimodal distribution peaking in the third and seventh decades of life. The age-specific incidence conformed to a J-shaped curve, indicating that most of these fractures are osteoporotic in nature. Tytherleigh-Strong et al. (1998) concluded that most of the humeral shaft fractures were simple injuries of elderly patients who are likely to be osteoporotic. Fractures of the young patients were often caused by a high energy injury in a road traffic accident or after falling from a height.

Humar shaft fractures can be classified according to site (upper third, mid-third and lower third) or by fracture morphology (transverse, oblique, spiral, spiral wedge or segmental) (Fig. 2) (Gregory 2001). McQueen et al. (1996) criticized descriptive classification according to site, because a fracture can occur between these thirds of a bone. The comprehensive AO classification (Fig. 3) is preferred in studies of humeral fractures (Müller et al. 1990, McQueen et al. 1996). The reproducibility of comprehensive classification, however, may be questioned and usually only AO types (A, B or C) or main classes (e.g. A1–3) are reproducible enough to allow communication between orthopaedic surgeons (Siebenrock & Gerber 1993, Flinkkilä et al. 1998). According to the study by Tytherleigh-Strong et al. (1998) 63% of the humeral shaft fractures were simple type A, 27% type B wedge fractures and 10% were comminuted type C fractures.

The incidence of open humeral shaft fractures in the study by Tytherleigh-Strong et al. (1998) was 5.6% of all fractures; 72% of these were simple grade 1 fractures according to Gustilo and Anderson’s classification (Gustilo & Anderson 1976).

Fig. 2. Transverse (a), oblique (b), spiral (c), spiral wedge (d) and segmental (e) fractures of the humeral shaft.
2.3 Treatment of humeral shaft fractures

Over the years many authors have advocated that uncomplicated humeral shaft fractures are most appropriately managed by nonoperative means (Watson-Jones 1955, Böhler 1965, Charnley 1974, Sarmiento et al. 1977, Ulrich 1996b, Gregory 2001, Sarmiento et al. 2001).

There is some evidence that nonoperative treatment is likely to fail in certain fractures or patients and early operation is recommended: multiple fracture patients, patients with concomitant chest trauma, bilateral fractures, ipsilateral humeral shaft and antebrachial fracture (floating elbow), fractures with articular extension, fractures with vascular injury, patients with ipsilateral brachial plexus injuries, certain open fractures, pathological fractures, severely obese patients, patients with poor cooperation, and if alignment is considered unacceptable in brace (Rogers et al. 1984, Bell et al. 1985, Foster et al. 1985,
Brumback et al. 1986, Flemming & Beals 1986, Schatzker & Tile 1987, Brien et al. 1990, Rosen 1990, Bleeker et al. 1991, Jensen & Rasmussen 1995, Ulrich 1996b, Modabber & Jupiter 1998, Gregory 2001, Sarmiento et al. 2001). Patients with concomitant lower extremity fracture benefit from operative stabilization of their humeral shaft fractures and usually they are able to carry some weight (Tingstad et al. 2000, Sarmiento et al. 2001). Fractures which are regarded as an indication of operative treatment, tend to be more displaced soft tissue injury is more extensive or additional injuries are present and therefore it is very difficult to compare results of nonoperative and operative treatment methods (Stern et al. 1984, Vander Griend et al. 1986).

Although nonoperative treatment is effective in simple humeral shaft fractures, nonunion does occur up to 10% of the cases and long-term impairment of the shoulder joint exists (Jupiter & van Deck 1998). In order to avoid these problems, there is growing interest in treating humeral shaft fractures operatively, despite the fact that there is little evidence of benefits of operative treatment (Heim et al. 1993, Rommens et al. 1995, Ulrich 1996a, Jupiter & van Deck 1998).

#### 2.3.1 Nonoperative treatment

As with all nonoperative treatment, some degree of malunion is inevitable in most cases if a humeral shaft fracture is treated nonoperatively (Sarmiento et al. 2001). There are no true criteria on how much deviation from anatomic alignment is acceptable for a good functional outcome after a humeral shaft fracture (Sarmiento et al. 1977, Sarmiento et al. 2001). The wide range of motion of the humerus at the shoulder joint allows acceptable function even with moderate malunion (Sarmiento et al. 2000). Klenerman (1966) suggested that acceptable alignment for the humerus is up to 20 degrees of anterior angulation, up to 30 degrees of varus angulation and up to 3 cm shortening. This amount of deformity does not sacrifice strength, range-of-motion (ROM) or cosmetic aspects (Klenerman 1966). Balfour et al. (1982) evaluated deformity in their study of nonoperatively treated patients and concluded that up to 15 degrees of varus angulation resulted in no detectable deformity, but deformities between 15–20 degrees could be seen, especially in thin patients. This data suggests that varus angulation greater than 15 degrees should probably not be accepted unless the patient is willing to accept visible deformity (Gregory 2001). Slight rotatory deformity is possible, but usually early function tends to correct this and clinical significance may be minimal, because great mobility of the shoulder joint can compensate for it (Fjalestad et al. 2000, Sarmiento et al. 2001).

Translation is well tolerated and bone contact is minimum what is needed to treat a humeral shaft fracture successfully nonoperatively (Sarmiento et al. 1977, Wallny et al. 1997a, Koch et al. 2002). Distraction of fragments carries an increased risk of nonunion (Charnley 1974, Sarmiento et al. 1977, Healy et al. 1987, Koch et al. 2002). There is some controversy as to whether or not proximal third fractures, transverse fractures, short oblique fractures, distal diaphyseal fractures and comminuted or segmental fractures are suitable for nonoperative treatment because of the considerable risk of delayed union or nonunion (Klenerman 1966, Loomer & Kokan 1975, Healy et al. 1987, Schatzker & Tile
1987, Wallny et al. 1997a). Some authors, however, have not considered these to be a problem (Zagorski et al. 1988, Sarmiento et al. 1990, Sarmiento et al. 2000, Pehlivan 2002).

Some authors recommend closed reduction of displaced fractures (Charnley 1974), whereas others regard it as useless, and even dangerous to radial nerve (Holstein & Lewis 1963, Sarmiento et al. 1977, Sarmiento et al. 2000, Koch et. al. 2002). Complete immobilization and complete closed reduction of fragments are impossible and in practice gravity reduces the fracture and a cast or brace is mainly for angular correction and immobilization (Charnley 1974, Sarmiento et al. 2001).

Primary radial palsy is not regarded as a contraindication of nonoperative treatment (Böstman et al. 1985, Böstman et al. 1986, Sarmiento et al. 2001)

The history of nonoperative treatment shows that many different methods, e.g. simple slings, thoracobrachial spica casts and traction and splinting techniques have been used, but no one method has proved to be the best (Ulrich 1996b). The introduction of the hanging cast by Caldwell and Rush brothers revolutionized nonoperative treatment and led to the invention of modern functional fracture treatments (Ulrich 1996b).

2.3.1.1 Hanging cast

The hanging cast is a long arm cast, which immobilizes the elbow joint at a 90-degree angle. The humerus is subjected to continuous traction by gravity. By adjusting the position of the arm, the fracture can be aligned differently. Although early mobilization of the joints has long been encouraged, shoulder joint exercises are impossible with a hanging cast and this leads inevitably to joint stiffness. Hanging cast treatments have been replaced by simpler nonoperative methods (Charnley 1974, Ulrich 1996b, Gregory 2001).

2.3.1.2 Coaptation splint

The coaptation splint (U-slab) is a U-shaped cast made of plaster. Lorentz Böhler is often cited as the inventor of this method (Ulrich 1996b). The coaptation splint gives support to the fracture and together with gravity aligns the fracture fragments. Excessive fracture distraction may result if soft tissue injury is extensive or the slab is too heavy. Shoulder and elbow joint mobilization with a coaptation splint is difficult and usually long-lasting stiffness is the result (Ulrich 1996b). The splint can be removed after 10–12 weeks, when the fracture does not show any clinical movement, is not tender and radiographs show bridging callus (Charnley 1974, Ulrich 1996b, Gregory 2001).

2.3.1.3 Functional bracing

Functional bracing was popularized by Agusto Sarmiento and Loren Latta in the 1970’s (Sarmiento et al. 1977). The fracture is initially immobilized with a U-slab. After pain
and swelling have subsided after 3–8 days, a brace is applied. The brace can be a prefabricated or custom-made plaster brace (Fig. 4) which immobilizes and aligns the fracture by applying pressure to the soft tissue envelopment. It is important to tighten the brace frequently when swelling subsides. Early function of the upper extremity is essential (Sarmiento et al. 1977, Sarmiento et al. 2000). Muscular contractions of agonist-antagonist pairs help to align the fragments and stimulate callus formation (Ulrich 1996b). A collar and cuff is used for pain relief and to prevent anteroposterior deformity up to 2 weeks. Active exercises of the elbow are started early, but only pendulum exercises of the shoulder are allowed during the first few weeks. Active exercises of the shoulder are started only after the fracture shows some consolidation after 4–6 weeks. The fracture usually consolidates in 10 to 12 weeks and use of the brace can usually be discontinued at that time (Sarmiento et al. 1977).

Functional bracing is regarded by many authors as the golden standard in the treatment of humeral shaft fractures (Sarmiento et al. 1977, Balfour et al. 1982, Zagorski et al. 1988, Wallny et al. 1997a, Sarmiento et al. 2000, Gregory 2001, Koch et al. 2002). Complications of functional bracing are rare (Sarmiento et al. 1999). Despite early mobilization, elderly patients are likely to develop prolonged shoulder stiffness and need a long period of rehabilitation (Ulrich 1996b, Koch et al. 2002). Long-term restriction in shoulder joint ROM exists, but it is usually minimal (Table 1, page 30). The nonunion rate ranges from 0% to 13% (Table 1).

Fig. 4. Functional brace of the humeral shaft.
2.3.2 Operative treatment

Most operative methods of treating humeral shaft fractures have been adopted from equivalent operations in the lower limb. When only a little malalignment is accepted in the treatment of lower extremity fractures, the same principles have also been applied to humeral shaft fractures, often without real evidence to support operative treatment in the humerus (Ulrich 1996b).

2.3.2.1 Compression plating

Since the introduction of AO principles DC plating has been the golden standard of operative fracture treatment (Müller et al. 1969, Schatzker & Tile 1987). Surgical incision in the humerus is usually anterolateral in proximal fractures, anterolateral or lateral in midshaft fractures and posterior in distal third fractures. The radial nerve has to be protected and in cases of radial palsy the nerve should be explored. Plate fixation requires accurate reduction and stable fixation of the main fragments. The lag screws give the best compression in oblique and spiral fractures, but in transverse and short oblique fractures dynamic compression should be applied. Depending on the size of the bone, a broad or narrow 4.5 mm DC plate is used, and screws have to have a purchase at least at 6 cortices on both sides of the fracture. In comminuted and segmental fractures, soft tissue dissection can be very extensive and rigid fixation can be difficult to achieve (Schatzker & Tile 1987, Ulrich 1996a, Sarmiento et al. 2001). Postoperative treatment is usually immediate mobilization of shoulder and elbow joints, but a protective brace can be used in cases of poor cooperation or poor bone quality (Schatzker & Tile 1987).

Soft tissue stripping from bone inevitably interferes with the normal bone blood supply, which may lead to problems of nonunion or infection (Cole 1996, Ulrich 1996a). Osteoporotic bone in older patients is often problematic and can lead to loss of fixation because of poor purchase of the screws (Ulrich 1996a). New fixed angle plates with locking screws may offer a solution to this problem (Pugh & McKee 2003).

Zimmermann et al. (1994), in biomechanical testing, compared AO compression plating with locking IM nailing and found that DC plating was superior in bending stiffness and rigidity, but torsion stiffness and rigidity were better in IM nails. Intramedullary nailing resulted constantly in a small gap at the fracture site whereas DC plating depended on accurately reduced bone and this explains the better bending properties of DC plating. Chen et al. (2002) compared the fixation stability of 10-hole DC plates with that of IM nails simulating comminuted fractures in their cadaver study, and they found that both methods offer similar stability in the humerus under physiological loads, but ultimate strength was better in the IM group. They regarded it as an advantage if early weight-bearing is needed in patients with multiple fractures.

Postoperative radial palsy is a major disadvantage of DC plating; the rate varies from 0% to 17% (Table 2). Infection is a relatively rare complication; the rate varies from 0% to 7% (Table 2). The nonunion rate ranges from 0% to 10% (Table 2, page 31). Reoperations may be needed because of fixation failure in 2% to 9% of cases (Table 2).
2.3.2.2 Intramedullary nailing

Most humeral shaft fractures, except those situated at the distal 2–3 cm of the diaphysis, are suitable for IM nailing (Pickering et al. 2002). There are several techniques and implants available. The nails can be divided into small calibre nails (e.g. Rush-pins, Ender), bundle nails (e.g. Hackenthal, Marchetti-Vicenzi), non-locking nails (Küntscher) and locking nails (e.g. Seidel, UHN, St Pro, Russel-Taylor) (Fig. 5). According to entry site, IM nailing can be either antegrade or retrograde (Fig. 6). The medullary canal can be enlarged (reamed) to achieve a better hold and allow larger nails to be used, or non-reaming techniques can be used (Ulrich 1996a, Pickering et al. 2002).¹

![IM nails: Rush-pin, Ender, Marchetti-Vicenzi, Küntscher, Seidel, UHN, St-Pro.](image)

Small and bundle nails provide enough stability to maintain alignment, but they usually do not provide rotational stability and external bracing is needed (Pickering et al. 2002). These nails can be inserted using retrograde or antegrade techniques and only a small hole is needed for Ender nails. Migration is a common problem with unlocked implants.

¹ Küntscher and Seidel nails manufactured by Howmedica, Kiel, Germany; UHN nail manufactured by Stratec Medical, Oberdorf, Switzerland; St-Pro nail manufactured by Biomet, Warsaw, IN, USA; Russell-Taylor nail manufactured by Smith & Nephew Richards, Memphis, TN, USA; Polarus nail manufactured by Acumed Inc, Beaverton, OR, USA; Marchetti-Vicenzi-nail manufactured by Zimmer, Warsaw, IN, USA.
and reoperations are often needed to remove nails, although this does not necessarily affect the final outcome (Foster et al. 1985, Pickering et al. 2002).

Locking nails have either transverse locking screws (UHN, St-Pro, Russell-Taylor and Polaris) or expandable fins (Seidel) at the distal end of the nail to offer rotational stability (Pickering et al. 2002). The latest invention is a nail which is expanded by hydrostatic pressure to sit tight along the bone and give rotatory stability (Franck et al. 2003).

A locking IM nail functions as an internal splint and in contrast to DC plating, completely rigid fixation across the fracture site cannot be achieved (Bechtold et al. 1996). Biomechanical testing of different nails shows that the quality of interlocking and rotational stability varies from nail to nail, those with loose interlocking allowing up to 30 degrees rotation at the fracture site (Dalton et al. 1993, Scopfer et al. 1994, Zimmermann et al. 1994, Lewis 1997, Blum et al. 1999, Molster et al. 2001). As previously mentioned, the ultimate strength of IM nails may be better than that of DC plates, but both implants probably withstand physiological loads equally well in the humerus (Zimmermann et al. 1994, Chen et al. 2002). Lin et al. (1998) recommended nailing from short segment to long segment, i.e. in proximal fractures an antegrade approach and in distal fractures a retrograde technique, because initial stability, torsional and bending stiffness was better using this construction. Good torsional stability of interlocking nails allows earlier postoperative mobilization than if small nails are used, but their effect on fracture union is controversial (Table 3).

Antegrade nailing (Fig. 6) is usually carried out with the patient in a beach-chair position. An anterolateral incision is made through the deltoid muscle. A small one-centimetre incision of the rotator cuff near the major tubercle of the humerus is made (Fig. 7). The medullary canal is opened with an awl. The fracture is reduced, closed if possible, and a guide pin is inserted through the fracture to the distal fragment. If a reaming technique is used, the reamer is passed over the guide wire and the canal is progressively enlarged. Usually a nail 1 mm smaller in diameter than the last reamer is used. The nail is driven in and locked. A guide jig is usually used with proximal locking screws and an open freehand technique using anterior or lateral screws is usually needed in distal locking to protect the radial nerve (Gregory 2001, Pickering et al. 2002). Mobilization is started as early as tolerated by the patient when interlocking nailing is used, but rotation is usually forbidden for three weeks if a Seidel nail is used (Pickering et al. 2002).

In the retrograde technique (Fig. 6), the patient is usually positioned prone. The medullary canal is opened 1–2 cm above olecranon fossa and a 2-cm hole is made in the humeral diaphysis in order to achieve a straight entry to the medullary canal. It is important not to use excess force when driving the nail in to avoid supracondylar iatrogenic fracture. Anterior or lateral placement of proximal locking screws is essential to avoid axillary nerve lesion (Gregory 2001, Pickering et al. 2002). Strothman et al. (2000) warned that retrograde insertion of an IM nail in the supracondylar area weakens torsional strength of the bone by 29% and entry via the olecranon fossa weakens it by 45%. Lin et al. (1998), however, found in biomechanical testing, that retrograde entry portal weakens bone by only 11%.
Fig. 6. Antegrade (a) and retrograde (b) locking nails (UHN).

Fig. 7. Antegrade access to the medullary canal through the supraspinatus tendon.

Vascular damage is inevitable every time a nail is driven into the medullary cavity (Cole 1996). Reaming disturbs cortical vascular supply even more, but it is restored during the following weeks (Rhinelander 1974, Rhinelander 1979, Reichert et al. 1995, Cole 1996, Olerud 1996). The effect of reaming on fracture healing is controversial. Reaming may
stimulate bone healing by means of bone grafting or periosteal callus formation and union rates in femoral and tibial fractures are better using reaming than nonreaming techniques and implants (Court-Brown et al. 1996, Tornetta & Tiburzi 1997). The reported humeral shaft union rates after nonreamed and reamed IM nailing are, however, very controversial (Sims & Smith 1995, Hems & Bhullar 1996, Blum et al. 1997). Riemer et al. (1994) reported a tendency towards nonunion in humeral shaft fractures that needed powerful reaming during insertion of Seidel nails in narrow diameter humeral shafts. Riemer (1996) later concluded that humeral fractures should be nailed using nonreaming techniques. Rommens et al. (1998a) recommended gentle hand reaming if a nail cannot be passed through the medullary canal otherwise.

Several authors have reported shoulder pain and stiffness after antegrade IM nailing (Table 3, page 32). Retrograde nailing may interfere with elbow joint function, but the effect is relatively short and there are only minimal long-term adverse effects (Rommens et al. 1995, Lin et al. 1997). The nonunion rate ranges from 0% to 33% (Table 3). The rate of postoperative radial nerve palsy is reported to range from 0% to 9% (Table 3). Infection is a rare complication; the reported rate ranges from 0% to 9% (Table 3). Iatrogenic fractures of narrow diameter humeral shafts during nailing have been reported by many authors (Table 3). Thermal or avascular necrosis has been described in the humerus after powerful reaming of a narrow intramedullary canal (Leunig & Hertel 1996, Reminger et al. 1997). Late fractures as a result of a new trauma below the nail tip have also been reported (McKee et al. 1996a). The axillary nerve may be at risk when inserting proximal locking screws if the nail is seated too deeply, but the actual rate of this complication is probably low (Lin et al. 1999). The lateral antebrachial cutaneous nerve may be at risk when inserting distal locking screws, but radial nerve lesion is rare if open techniques are used during distal locking (Moran 1995, Blyth et al. 2003).

### 2.3.2.3 External fixation

Despite the fact that early on some fracture surgeons achieved success using external fixation (EF) devices for closed humeral shaft fractures, the method did not become popular and only a few surgeons have reported results of this method (De Bastiani et al. 1984, Ulrich 1996a). Most authors agree that EF should be reserved for open fractures with severe soft tissue injury (Mostafavi & Tornetta 1997, Zinman et al. 1997, Johnson & Strauss 2003). Open fractures with mild to moderate soft tissue injuries (Grade I–IIIa) can usually be treated nonoperatively or with internal fixation after adequate soft tissue coverage (Putnam & Walsh 1993, Balfour & Marrero 1995, Johnson & Strauss 2003). Open fractures with severe soft tissue injuries (Grade IIIb–IIIc), which are associated with neurovascular injuries or gross contamination are best managed with emergency EF (Mostafavi & Tornetta 1997, Zinman et al. 1997). Infected nonunion may also be a good indication for EF in the humerus (Chen et al. 1997). Pin tract infection is a major disadvantage of EF of the humerus, because pins penetrate a thick soft tissue sleeve and probably rotation of the upper extremity irritates pin tracts (Ulrich 1996a).
2.3.3 Radial nerve palsy

Radial nerve palsy is associated with about 8–11% of fractures of the humeral shaft (Shaw & Sakellarides 1967, Mast et al. 1975, Pollock et al. 1981, Böstman et al. 1985). The nerve is most vulnerable in distal third fractures, where it pierces the intermuscular septum (Holstein & Lewis 1963, Gregory 2001). Usually the problem is stretching of the nerve during injury, causing neurapraxia or axonal injury, but total severance of the nerve is also possible in closed injuries (Holstein & Lewis 1963, Takami et al. 1999). Late onset paresis has also been described, but it is considered to be very rare (Chesser & Leslie 2000).

Any humeral shaft fracture may be associated with radial nerve palsy, but a spiral fracture at the distal third of the humerus with lateral and varus displacement of the distal fragment (Holstein-Lewis fracture) is especially likely to be associated with radial nerve palsy because the nerve is easily entrapped in the fracture (Holstein & Lewis 1963).

If open fractures caused by gunshots or penetrating objects are associated with primary radial palsy, the nerve should be explored and repaired at the time of wound debridement or closure (Dabezies et al. 1992, Foster et al. 1993). Also, if radial paresis develops after closed manipulation, immediate exploration should be carried out, because the nerve can be entrapped between fracture fragments (Sarmiento et al. 2001).

There is, however, some debate over how to treat radial nerve paresis in cases of closed fractures (Ulrich 1996b). The probability of spontaneous recovery in 5–7 months is high, an 80–100% recovery rate has been reported and early exploration does not improve recovery (Sarmiento et al. 1977, Böstman et al. 1986, Zagorski et al. 1988, Sarmiento et al. 1990, Sarmiento et al. 2000). Most authors do not regard primary radial palsy as an indication for surgery (Böstman et al. 1985, Larsen & Barfred 2000, Sarmiento et al. 2001). As the results of late radial nerve explorations with or without nerve repair, which may involve nerve grafting, are usually poor, some authors feel that early exploration with plating of the fracture is justified (Pollock et al. 1981, Schatzker & Tile 1987). If nerve function has not recovered by 3–4 weeks, the injury is an axonotmesis or neurotmesis and although early exploration does not improve recovery of the nerve in cases of axonotmesis, primary nerve repair is still possible in cases of neurotmesis at that time (Schatzker & Tile 1987).

Closed manipulation or IM nailing of Holstein-Lewis fractures may be associated with a high risk of radial nerve lesion and open techniques are preferred if operative treatment is needed (Holstein & Lewis 1963, Lin 2002). Lin (2002) found a high incidence of radial nerve entrapment between fracture fragments in high energy external rotation injuries causing a spiral fracture at any level of the humerus. Closed IM nailing of these is associated with a high risk of radial nerve injury and exploration with cerclage wiring at the time of nailing may be justified (Lin 2002).

If surgery is needed in closed fractures with radial nerve palsy, open reduction and DC plating is regarded as the best way to treat these injuries (Schatzker & Tile 1987, Gregory 2001, Pickering et al. 2002). Closed IM nailing is not recommended in cases of primary radial nerve palsy, but if nailing is carried out the radial nerve should be explored (Lin 2002). Radial nerve lacerations due to reaming, although rare, have also been described (Farragos et al. 1999).
2.3.4 Results of treatment

Publications on humeral shaft fractures can be divided into follow-up studies, comparative studies and prospective randomized trials. The results of follow-up studies in regard to different treatment methods must be cautiously analyzed because in general those fractures treated operatively tend to be problem fractures (Vander Griend et al. 1986). Operatively treated fractures are often more displaced, soft tissue injury may be worse as a result of high energy trauma, there are more open fractures, and patients may have associated lower extremity fractures or neural and skeletal injuries of the same extremity (Stern et al. 1984, Vander Griend et al. 1986). In addition, the criteria of good functional outcome vary between studies greatly. Comparison of union rate is probably more reliable than comparison of functional results.

Table 1. Results of nonoperative treatment in follow-up studies.

<table>
<thead>
<tr>
<th>Authors</th>
<th>N</th>
<th>Method</th>
<th>Joint impairment* (% of cases)</th>
<th>Nonunion (%)</th>
</tr>
</thead>
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<tr>
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<td>51</td>
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<td>127</td>
<td>Functional bracing</td>
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<td>2</td>
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<td>Sarmiento et al. 1990</td>
<td>85</td>
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<td>Ciernik et al. 1991</td>
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<td>Hanging cast</td>
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<td>39</td>
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<tr>
<td>Jensen &amp; Rasmussen 1995</td>
<td>35</td>
<td>Functional bracing</td>
<td>-</td>
<td>11</td>
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<tr>
<td>Walny et al. 1997a</td>
<td>87</td>
<td>Functional bracing</td>
<td>14**</td>
<td>6</td>
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<td>13</td>
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<td>Pehlivan et al. 2002</td>
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</table>

*Limited ROM/pain in shoulder or elbow joints
**Mild restriction in external rotation
Table 2. Results of plate fixation (ORIF) in follow-up studies.

<table>
<thead>
<tr>
<th>Authors</th>
<th>N</th>
<th>Joint impairment* (% of cases)</th>
<th>Nonunion (%)</th>
<th>Radial nerve# (%)</th>
<th>Infection (%)</th>
<th>Fixation failure (%)</th>
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<td>-</td>
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* Limited ROM/pain in shoulder or elbow joints
# Postoperative radial nerve paresis
** Severe skeletal or soft tissue injuries in the same extremity
Table 3. Results of IM nailing in follow-up studies.

<table>
<thead>
<tr>
<th>Authors</th>
<th>N</th>
<th>Method</th>
<th>Joint impairment* (% of cases)</th>
<th>Non-union (%)</th>
<th>Radial nerve# (%)</th>
<th>Infection (%)</th>
<th>Iatrogenic comminution (%)</th>
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<td>-</td>
<td>6</td>
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<td>Sanzana et al. 2002</td>
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</table>

* Limited ROM/pain in shoulder or elbow joints
# Postoperative radial nerve paresis
a = antegrade r = retrograde a/r = ante- or retrograde

According to the results of follow-up studies, functional bracing (Table 1) is associated with a 0–13% risk of nonunion. The shoulder or elbow joint is disturbed in 0–38% of the patients. No other complications have been reported. The nonunion rate in DC plating (Table 2) is a little lower, 0–10%, but this technique is associated with a considerably high risk of iatrogenic radial nerve lesion (0–17%), infection (0–7%) and fixation failure (0–9%), likely to lead to reoperation. The nonunion rate after IM nailing (Table 3) is very controversial (0–33%), shoulder/elbow joint impairment is frequent (0–90%), but radial
nerve lesion less frequent (0–9%) than in DC plating. Technical problems lead to iatrogenic fractures in 0–46% of the cases.

There are several retrospective comparative studies of different treatment methods. Zatti et al. (1998) compared retrograde flexible nailing (14 patients) with DC plating (16 patients) in their retrospective study. They did not find any significant difference in healing time or function, but complications were less frequent in the flexible nailing group.

Lin (1998) compared antegrade locked nailing (48 patients) with plate fixation (25 patients) in their retrospective study. Union rate and shoulder function did not show any significant differences and the authors preferred IM nailing to ORIF because IM nailing is minimally invasive and complications less common. Wallny et al. (1997b) compared functional bracing (44 patients) and antegrade interlocking nailing (45 patients) in their retrospective study. Fracture union and functional results did not show any significant differences.

Blum et al. (2001) compared antegrade (27 patients) and retrograde (57 patients) unreamed IM nailing of the humerus in their retrospective study. They did not find any difference in functional outcome, but iatrogenic comminution and nonunion was more common in those treated by means of the retrograde technique. They concluded that bone healing problems are rather surgeon-related than approach-related.

Scheerlinck & Handelberg (2002) compared retrograde Marchetti-Vicenzi nailing (30 patients) with antegrade AO nailing (22 patients) in their retrospective study. Two fractures with Marchetti-Vicenzi nails and one with an AO nail needed reoperation because of nonunion. The antegrade route more often resulted in shoulder ROM limitation and weaker abduction power than retrograde Marchetti-Vicenzi nailing.

Meekers & Broos (2002) compared DC plating (80 patients) with unreamed retrograde IM nailing (81 patients) in their retrospective analysis. Two fractures with Marchetti-Vicenzi nails and one with an AO nail needed reoperation because of nonunion. The antegrade route more often resulted in shoulder ROM limitation and weaker abduction power than retrograde Marchetti-Vicenzi nailing.

There are three published prospective randomized comparative studies of different methods of treating humeral shaft fractures. Chiu et al. (1997), in their prospective randomized study, compared DC plating (30 patients), DC plating with bone grafting (29 patients) and Ender nailing (ante- or retrograde) (32 patients). All fractures united and there was no difference in function.

Chapman et al. (2000), in their prospective randomized study, compared antegrade IM nailing (38 Russell-Taylor nails) and DC plating (46 patients). Shoulder pain and restriction in ROM were associated with IM nailing, whereas restricted ROM in the elbow was associated with ORIF. Union and complication rates were equal. They concluded that both methods can be used in the treatment of humeral shaft fractures.

McCormack et al. (2000), in their randomized prospective study compared IM nailing (14 antegrade, 9 retrograde Russell-Taylor nails) and DC plating (22 patients) and found no difference in ASES (American Shoulder and Elbow Surgeons) scores, shoulder pain, shoulder ROM or elbow function. The union rate was similar, but reoperations because of
shoulder impingement were needed in the IM nail group. They concluded that DC plating is to be preferred over IM nailing.

It is very difficult to draw any definitive conclusions from published comparative studies as to which treatment method is most appropriate for a humeral shaft fracture. Most authors agree that there is no evidence that operative treatment is better than nonoperative treatment of simple humeral shaft fractures (Ulrich 1996a, Gregory 2001, Sarmiento 2001). Operative treatment is likely to be associated with a relatively high risk of complications, and indications may be exceptional (Ulrich 1996a).

When operative indications exist, most authors agree that humeral shaft fractures are most appropriately operated on using DC plating, because of the higher probability of shoulder problems associated with antegrade IM nailing and problems with reconstruction of nonunion after IM nailing (Gregory & Sanders 1997, Modabber & Jupiter 1998). When DC plating is difficult, as in comminuted and segmental fractures, IM nailing is considered suitable (Sarmiento et al. 2001, Lin & Hou 2003).

2.4 Nonunion of the humeral shaft

Although relatively rare, failure to achieve union after humeral shaft fracture continues to be a serious clinical problem (Jupiter & van Deck 1998). The Association for the Study of Internal Fixation (ASIF) has defined the term delayed union as a fracture that has not healed at 4 months and nonunion is defined as a fracture that has not healed at 8 months (Weber & Cech 1976). Persistent pain and no radiological signs of union in a series of radiographs can predict non-union earlier (Weber & Cech 1976). Mast et al. (1975) found that those humeral shaft fractures that did not show clinical or radiographic signs of union by 6–10 weeks were likely to progress to nonunion. Sarmiento et al. (1977) reported the mean healing time of a humeral shaft fracture to be about 10 weeks. Most authors agree that in the humerus a nonunited fracture at 6 months can be regarded as nonunion (Mast et al. 1975, Foulk & Szabo 1995, Jupiter & van Deck 1998).

Various factors have been recognized as risk factors of nonunion: fracture pattern (transverse, short oblique, multifragmented), associated medical conditions (obesity, osteoporosis, alcoholism), soft tissue interposition, overdistraction of the fracture and inadequate immobilization or internal fixation (Jupiter & van Deck 1998, Sarmiento et al. 2001). Operative treatment of acute fractures represents a major source of complications of healing (Jupiter & van Deck 1998).

2.4.1 Treatment of nonunion after nonoperative treatment

There is little disagreement that nonunion of the humeral shaft after nonoperative treatment needs operative treatment (Ulrich 1996a, Jupiter & van Deck 1998). Surgical treatment should be considered as early as 12–16 weeks after the injury, if good closed treatment has failed (Sarmiento et al. 2001). Patients who do not have pain, who are able to perform everyday activities or who have medical conditions that would make surgery too dangerous are not good candidates for operative treatment.
The appropriate treatment method is chosen on the basis of biological and mechanical characteristics. Atrophic nonunion needs a biological stimulus, usually autologous bone grafting, in addition to stable fixation, but hypertrophic nonunion reflecting a well vascularized environment in general needs only stable fixation (Jupiter & van Deck 1998).


In cases of well-aligned hypertrophic nonunion, closed IM nailing may be considered (Küntscher 1962, Hempel & Fisher 1980, Ulrich 1996a, Jupiter & van Deck 1998). Webb et al. (1985) reported IM nailing to be an effective method of treatment of femoral shaft nonunion. Intramedullary nailing is also effective in tibial nonunion after nonoperative treatment (Alho et al. 1993). However, in the humerus the results have not been universally good (Jupiter & van Deck 1998). Christensen (1976) reported Küntscher nailing to be effective in the treatment of humeral shaft nonunion. In his series of 13 patients IM nailing was successful in 10 cases (77%) and he felt that those left with nonunion did well, because the nail could control alignment. Foster et al. (1985) found DC plating to be more effective (union rate 80%) than Küntscher nailing (union rate 73%) in the treatment of nonunion of the humeral shaft in 21 patients. Lin et al. (2000) reported Seidel nailing to be effective (union rate 95%) in the treatment of delayed union or nonunion of the humeral shaft, but 50% of their cases were complications of operative treatment and 38 of their 41 cases were nailed using open techniques with additional bone grafting. Later, Lin et al. (2002) recommended additional interfragmentary wiring to add compression along the nonunion line. Wu & Shih (1992) compared DC plating with bone grafting versus antegrade Seidel nailing with bone grafting in their retrospective study of 35 patients. There was no difference in union rate (87%) or shoulder joint function, but complications were more frequent in the ORIF group (21% vs. 12%). Most (29) of the 35 patients had had previous operations because of disturbed fracture healing. Schwartz & Posch (1995) reported unsatisfactory results using Seidel nails in nonunion, resulting in union in 8/12 patients. Intramedullary nailing was the first operation in 11 patients.

External fixation or Ilizarov’s technique are effective methods to treat nonunion, but usually these techniques in the humeral shaft are reserved for complicated cases such as infected nonunion (Ciuccarelli et al. 1990, Catagni et al. 1991, Cattaneo et al. 1993, Jupiter & van Deck 1998, Lavini et al. 2001, Martinez et al. 2001).
2.4.2 Treatment of nonunion after compression plating and IM nailing

There are no papers especially addressing the treatment of nonunion of the humeral shaft after plate fixation. The most appropriate treatment consists of removal of loose hardware, shortening of the bone ends, fixation of the nonunion with longer plates (8 holes at least) and autologous bone grafting (Healy et al. 1987, Jupiter & van Deck 1998, Pugh & McKee 2003). Reported union rates range from 80% to 96% (Jupiter & van Deck 1998). The operation should be carried out early, because loose hardware can lead to problems in cases of poor bone quality (Jupiter & van Deck 1998).

Nonunion after IM nailing (Fig. 8) is a different problem to that after nonoperative treatment or plate fixation. Information on the treatment of nonunion after IM nailing mainly comes from femoral and tibial fractures. Webb et al. (1986) reported repeated nailing with over-reaming as an effective method to treat delayed union after IM nailing of femoral diaphyseal fractures. Court-Brown et al. (1994) reported the same procedure, exchange nailing, to be effective (100% union in fractures without bone loss) in delayed union and nonunion after IM nailing of tibial fractures. These good results have also been reproduced in other studies, the reported union rate being 92–100% (Templeman et al. 1995, Furlong et al. 1999, Wu et al. 1999, Hak et al. 2000).

The proposed mechanism by which exchange nailing enhances bone union is exposure of bleeding bone, which can induce callus formation (Court-Brown et al. 1994). Reaming, though interfering with endosteal circulation, is considered to result in an increase of blood supply to the bone through an increase in periosteal blood flow (Reichert et al. 1995). Bone healing after exchange nailing in cases of tibial and femoral nonunion is mainly periosteal (Court-Brown et al. 1994, Wu et al. 1999, Furlong et al. 1999).

There are only a few reports dealing with exchange nailing in cases of humeral shaft nonunion after IM nailing (Robinson et al. 1992, McKee et al. 1996b, Farragos et al. 1999). Robinson et al. (1992) reported 5 cases of nonunion after IM nailing of humeral shaft fractures and exchange nailing was successful in only 2 cases. McKee et al. (1996b) reported similar results, the procedure being successful in 4 cases out of 10. Lin et al. (2003b), however, reported good results of exchange nailing with bone grafting in their series of 23 patients. Supplementary interfragmentary wiring was used in 17 cases and the operation was successful in 22 patients.

Other treatment methods have also been used to treat nonunion of the humeral shaft after IM nailing. Wu et al. (1998) reported bone grafting and staple augmentation to be effective in the treatment of nonunion after Seidel nailing. They proposed that rotational instability was controlled by the staple and this was essential in the procedure. Emmerson and Sher (1998) used additional plate fixation successfully in three cases of nonunion after Seidel nailing. They did not remove the nail, they used a short plate and bone grafting and regarded this method as effective in the treatment of this condition. Recently Gerber et al. (2003) reported a similar operation in 6 cases of nonunion after IM nailing. They used a specially contoured plate, a wave plate, which allows bone grafting under it.

McKee et al. (1996b) regarded ORIF with nail removal and bone grafting as the best method to treat nonunion after IM nailing. This procedure was successful in all nine cases in their series. Other authors have confirmed their results (Wright 1997, Ring et al. 1997).
If ORIF with bone grafting is used, it should be carried out before severe osteolysis develops (Farragos et al. 1999).

Fig. 8. Nonunion after Seidel and St-Pro IM nailing.

### 2.4.3 Treatment of nonunion with poor bone stock

Long lasting nonunion especially with a loose IM nail or after several operations, may result in nonunion with poor bone stock at the fracture site (Fig. 9), which can make treatment very difficult (Farragos et al. 1999). The windshield wiper-like effect of a loose nail results in osteolysis of diaphyseal bone, jeopardizing cortical integrity (McKee et al. 1996b, Farragos et al. 1999, Lin et al. 2003a). This condition is typical of the humeral shaft and seldom seen in nonunion after IM nailing of femoral or tibial fractures (Farragos et al. 1999). Poor purchase of screws in compromised bone makes internal fixation very difficult and loosening of the implant often follows (McKee et al. 1996b). Special techniques may be needed to reconstruct these difficult cases of nonunion (Jupiter & van Deck 1998).

Wright (1997) reported 19 cases of humeral shaft nonunion with multiple operations and compromised bone stock, involving intramedullary quadricortical fibular allografting, iliac crest autografting and plate fixation. Intramedullary nailing had been
used in primary operations in 12 patients. Union was achieved in 17 cases. Two cases of radial nerve paresis occurred, but no deep infections. Crosby et al. (2000) also reported good results (union 10/12), using similar operations. They did not report any cases of nonunion after IM nailing. Hornicek et al. (2001) used onlay bone plate allograft augmentation in 10 cases of humeral shaft nonunion. Five of their cases involved nonunion after IM nailing. Four of these united. Radial nerve paresis complicated two cases, but no deep infections occurred. Jupiter (1990) and recently Muramatsu et al. (2003) successfully used vascularized fibular autografting in difficult cases of nonunion involving compromised bone.

Open methods necessitate extensive soft tissue dissection and often radial nerve mobilization, which carries a high risk of iatrogenic radial nerve palsy (Farragos et al. 1999, Lin et al. 2003a). Infection can also be a major problem, because of scarred soft tissues (Farragos et al. 1999, Lavini et al. 2001).

External fixation using a ring fixator, and gradually compressing the nonunion site without opening the fracture, Ilizarov’s technique, is a well-known procedure especially in the treatment of complicated nonunion (Ilizarov 1988). In the humerus, however, this technique is considered difficult (Jupiter & van Deck 1998). There are only a few reports dealing with Ilizarov’s technique in the treatment of nonunion of the humeral shaft after locking IM nailing. Raschke et al. (1998) reported one case which was successfully treated using Ilizarov’s technique. Patel et al. (1999) reported excellent results of this technique in 11 patients with nonunion after IM nailing. They used compression over the nail without opening the fracture in 10 cases and removed the nail only in one case. The frame was a hybrid one with combined small wires and half-pins. Minor pin tract infection was a common complication. Menon et al. (2002) reported good results in 4 cases of humeral shaft nonunion after IM nailing. They used compression over the nail with small intracortical wires. Lammens et al. (1998) reported on 13 patients with nonunion after failed locking nail treatment. They removed the nail and compressed the fracture until union occurred. Premature removal of the frame led to refracture in four cases and these were treated by using a new frame. Kocaoglu et al. (2001) reported 35 cases of humeral shaft nonunion which were treated by using Ilizarov’s technique, with good results. Only 5 cases were nonunions after IM nailing. Pin tract infection was the most common problem, leading to frame removal in three cases, but this did not have an effect on the outcome. Radial nerve paresis complicated three cases. These reports on Ilizarov’s technique have not addressed the problems of compromised bone quality in cases of nonunion after IM nailing.
2.5 Pathological fractures of the humeral shaft

About 10% of humeral fractures are caused by metastasis of a malignant tumour (McQueen et al. 1996). The humerus is the second-most common long bone after the femur to be affected by metastasis, accounting for 16% of all pathological fractures (Redmond et al. 1996). Pathological fractures of the humeral shaft (Fig. 10) are usually simple A-type fractures (Tytherleigh-Strong et al. 1998). The most common underlying malignant diseases that send metastases to the long bones are breast, prostate, kidney, lung and thyroid cancer (Habermann & Lopez 1989).

Unlike in the lower extremity, pathological humeral shaft fractures have been treated nonoperatively until relatively recently, which has often resulted in nonunion with severe pain and disability (Douglass et al. 1976, Flemming & Beals 1986, Lancaster et al. 1988, Habermann & Lopez 1989). Today there is only little disagreement that pathological humeral fractures or impending fractures (Fig. 10) need operative treatment (Flemming &
Beals 1986, Habermann & Lopez 1989, Van Geffen et al. 1997). The questions are, however, which method to use and is the patient well enough to undergo an operation with considerable risks (Pritchard 1992). Patients with metastatic bone disease frequently suffer from malnutrition, general muscle weakness, respiratory insufficiency and hypercalcaemia (Van Geffen et al. 1997). These factors combined with chemotherapy predispose patients to various complications (Van Geffen et al. 1997).

A pathological fracture is usually a sign of progressive disease and operative treatment of these fractures does not improve the prognosis of the disease, but improves quality of life and nursing (Douglass et al. 1976, Sim & Pritchard 1982, Lancaster et al. 1988). It is generally accepted that survival after pathological fracture is determined by the nature of the primary tumour, not the treatment of the fracture (Vail & Harrelson 1991). The average survival time after pathological fracture has ranged from 4 to 15 months in different reports (Sim et al. 1974, Harrington et al. 1976, Lancaster et al. 1988).

Open reduction and internal fixation (ORIF) with polymethylacrylate (PMMA) cementing has previously been used with success for diaphyseal lesions (Harrington et al. 1976, Dijkstra et al. 1994, Van Geffen et al. 1997). Extension of a metastatic lesion may be far beyond the radiographic signs and therefore plate fixation may easily fail (Harrington 1995). Long plates with intramedullary PMMA cement augmentation may prevent this complication, but extensive exposure is needed (Harrington 1995). Highly vascular tumours like renal carcinoma can result in extreme blood loss during or after the operation (Dijkstra et al. 1996). Often the lesion has been irradiated before operation and in scarred tissue the risk of radial nerve damage is high (Harrington 1995). Radical excision of the lesion and internal fixation with a PMMA spacer has also been suggested as an effective method, but this increases risks significantly and it is questionable whether radical excision improves prognosis (Sabato & Stein 1983, Vandevyer & Gebhart 1997). Radical treatment may be considered when there is a small solitary metastasis from a slowly growing tumour, such as hypernephroma (Sim & Pritchard 1982).

Some authors have reported good results with small calibre IM nails (Rush, Ender, Hackenthal) together with PMMA fill of the metastasis (Lewallen et al. 1982, Kunec & Lewis 1984, Lancaster et al. 1988, Vail & Harrelson 1991). Lancaster et al. (1988) reported that reoperations were needed because of prominent nail tips, but migration was prevented by PMMA. Recently Kumta et al. (2002) reported good results with no complications using closed retrograde Ender nails to treat pathological fractures of the humeral shaft. Redmond et al. (1996) reported results of closed antegrade locking IM nailing in the treatment of 13 pathological humeral shaft fractures. There was minimal blood loss, short operative time, no complications or reoperations and good pain relief. Dijkstra et al. (1996) compared plate fixation plus PMMA fill with IM nailing. Patients who underwent ORIF had more systemic complications, but the difference was not significant and they concluded that both methods can be used effectively and safely. Franck et al. (2002) reported results after using an expandable IM nail and an antegrade technique. The operative time was short, no complications occurred and pain relief was consistently good.

Reaming of the medullary canal may theoretically cause dissemination of tumour cells to healthy bone or into the circulation and seed distant metastases (Habermann & Lopez 1989). However, this has never been proven in clinical practice (Dijkstra et al. 1996).
New non-reaming techniques and interlocked nails may offer suitable alternatives to reaming (Eingartner et al. 1997).

Postoperative irradiation may provide local control of the tumour and pain relief (Cheng et al. 1980). Large doses of irradiation have a negative effect on fracture healing, but nonunion is usually no problem among these patients, because of their short life expectancy (Bonarigo & Rubin 1967, Harrington et al. 1976). Townsend et al. (1995) reported better functional status in patients with postoperative irradiation of weight-bearing bones. There were also fewer reoperations among irradiated patients. The mean survival time was statistically significantly better for irradiated patients in this retrospective study. Van Geffen et al. (1997), in contrast found more bone-related complications, implant loosening and nonunion among patients who had received radiotherapy compared with those treated without irradiation. Postoperative irradiation did not provide any pain-relieving effects in their retrospective study. Irradiation of impending fractures can slow down the growth of a lesion and operation may be avoided (Cheng et al. 1980). Early operative stabilization of an impending fracture (Fig. 10) may result in better function and pain control than irradiation alone (Van Geffen et al. 1997).

Fig. 10. Metastasis (breast cancer) of the humeral shaft and impending pathological fracture (a). Pathological fracture of the humeral shaft (multiple myeloma) (b).
2.6 Impairment of shoulder joint function after humeral shaft fracture

Numerous studies have shown that shoulder joint function may be impaired after humeral shaft fractures, independent of the treatment method used (Tables 1–3). The most controversial issue is whether or not antegrade IM nailing is associated with more problems in the shoulder joint than nonoperative treatment or DC plating (Chapman et al. 2000, McCormack et al. 2000).

2.6.1 Pain

Shoulder joint pain has not been recognized as a major problem after nonoperative treatment or plate fixation, although patients may feel ill-defined pain at the fracture site years after fracture (Farragos et al. 1999, Sarmiento et al. 2001). Shoulder pain has been associated mainly with antegrade IM nailing (Table 3). Migration of unlocked implants into the subacromial space is a common problem causing mechanical impingement (Stern et al. 1984, Foster et al. 1985). Locked implants do not migrate and if the nail is seated properly hardware should not cause any problems (Riemer 1996). Most investigators regard rotator cuff impingement as the most important factor causing shoulder problems (Stern 1984, Riemer 1996, Farragos et al. 1999, Pickering et al. 2002). Incision of the supraspinatus tendon is made near a so-called critical zone in the tendon which has been believed to have poor blood supply, leading to healing problems in the tendon and subacromial impingement follows (Farragos et al. 1999). However, later studies have shown that this area is in fact hypervascular and even degenerative rotator cuff ruptures of this zone heal after surgical treatment (Chansky & Iannotti 1991, Uhthoff & Sarkar 1991, Brooks et al. 1992). Therefore, it is unclear if tendon-healing problems are the main reason for shoulder joint impairment.

Riemer et al. (1993) discussed the site of incision, and they preferred incision anterior to the acromion instead of lateral incision. They recommended that the nail should not be inserted at the junction of the major tubercle and articular cartilage, but more medially where an incision in the supraspinatus tendon is in an area where the blood supply is better. Lin et al. (1999) criticized this entry site, because it inevitable violates articular cartilage of the humeral head. Riemer (1996) also reported that coracoacromial ligament division was essential to decompress the subacromial space. A lateral approach may tear the lateral aspect of the coracoacromial ligament and cause inflammation and impingement (Riemer 1996). With transsection of the coracoacromial ligament Riemer et al. (1993) reported a 95% rate of excellent shoulder function in their study of 51 patients.

Numerous complications associated with IM nailing may require several reoperations, and repeated access to the nail through the rotator cuff can be a serious problem (Hems & Bhullar 1996). Some authors have recognized proximal locking screws protruding into the deltoid muscle as the main reason for shoulder pain and discomfort (Ikpeme 1994). Older patients seem more likely to have pain problems (Sarmiento et al. 2001).
### 2.6.2 Range-of-motion

Most authors agree that immobilization needed in nonoperative treatment leads in most patients to some degree of loss in ROM of the shoulder joint (Table 1). Ciernik et al. (1991) reported restricted ROM after hanging cast treatment of 23 humeral shaft fractures. The limitations were minimal and did not cause any trouble in everyday tasks. Slightly restricted external rotation in 30–40% of patients who have undergone nonoperative treatment has also been described (Klenerman 1966, Fjalestad et al. 2000). Koch et al. (2002) also noted slight restriction in ROM of the shoulder joint in 40% of patients. Patients older than 40 years were at a greater risk of having motion loss, especially external rotation, compared with younger patients. Old age has also been recognized as a risk factor as regards restriction in ROM in other work (Sarmiento et al. 2001). Fjalestad et al. (2000) considered union in malrotation as the main reason for loss of external rotation.

Impairment of the shoulder and elbow joints after DC plating of humeral shaft fractures is usually associated with concomitant soft tissue, neurological or skeletal injury of the same extremity (Vander Griend et al. 1986). Surgical incision has not been described as causing any problems in function of the shoulder joint, but posterior incision does cause impairment in elbow extension (Chapman et al. 2000).

Many authors have described restricted ROM after antegrade IM nailing (Table 3). Lin & Hou (2000) reported rotational malalignment after both antegrade and retrograde nailing, but this probably affects shoulder joint function minimally. A prominent nail tip in the subacromial space has been recognized as a major problem, as well as migration of unlocked nails (Robinson et al. 1992).

Comparative studies of shoulder joint function give confusing results compared with follow-up studies (Table 3). Chapman et al. (2000) compared antegrade IM nailing and DC plating in their prospective randomized study. They found that there was a tendency for those treated with IM nails to have more shoulder pain and restriction of ROM and those treated by DC plating had more elbow pain and restriction in ROM. They concluded that they could demonstrate no significant differences in healing outcomes of these two treatment methods. McCormack et al. (2000) found no differences in ROM, pain scores, ASES scores or union rate in their prospective randomized study of IM nailing and DC plating. Subacromial impingement necessitating nail removal, and postoperative radial nerve palsy were more common in the IM nailing group. Scheerlink & Handelberg (2002) reported decreased shoulder joint ROM and abduction strength after antegrade nailing compared with retrograde bundle nailing. Wallny et al. (1997b) compared nonoperative treatment and antegrade IM nailing and found no statistically significant difference in ROM between these groups.

### 2.6.3 Strength

Recovery of shoulder muscle strength after humeral shaft fracture has received very little attention. Mast et al. (1975) reported isokinetic measurement (Cybex) of shoulder and elbow muscle strength to be useful in the assessment of functional results after humeral
shaft fractures, but there have not been any further studies on this subject. Scheerlink & Handelberg (2002) reported decreased isometric abduction strength after antegrade locked IM nailing compared with retrograde Marchetti-Vicenzi nailing. Only isometric abduction strength was measured as a part of Constant scoring. There are no published papers on shoulder muscle strength recovery after humeral shaft fractures.
3 Aims of the present study

The purpose of the present study was to assess the role of antegrade IM nailing in the treatment of humeral shaft fractures. The following specific points were addressed:

1. To study, in a consecutive series of humeral shaft fractures, union rate, shoulder joint function and symptoms after antegrade IM nailing, to confirm previously published results, and to study the effect of postoperative fracture distraction in fracture union (I).
2. To assess efficacy and safety of IM nailing in the treatment of pathological fractures of the humeral shaft (II).
3. To find out if exchange nailing is effective in the treatment of nonunion after IM nailing of humeral shaft fractures (III).
4. To assess Ilizarov’s technique in the treatment of nonunion with compromised bone quality after IM nailing (IV).
5. To study whether the antegrade technique is the main reason behind shoulder joint impairment, by comparing shoulder joint symptoms, ROM and strength after antegrade IM nailing and DC plating of humeral shaft fractures (V).
4 Patients and methods

The study consists of five sub-studies. The patients in each study were either originally treated at or referred to Oulu University Hospital because of problems in fracture healing.

4.1 IM nailing of fractures of the humeral shaft (I)

The patients in this study (I) consisted of 125 patients with 126 humeral shaft fractures which were operated upon by using antegrade intramedullary nailing during the years 1987–1997. The patients’ (71 females, 54 males) mean age was 60 (17–90) years. The mechanism of injury was falling or slipping in most cases and 13 patients (10%) had polytrauma mainly as a result of a traffic accident. There were 74 acute fractures, 17 pathological fractures caused by a metastatic disease, 16 fractures with persistent malalignment in a hanging cast or brace, 15 fractures with delayed union (failure of consolidation in 2 months) or nonunion (failure of union in 6 months) and 4 fractures associated with failed ORIF. Ten patients (8%) had primary radial nerve palsy.

The operative technique was antegrade closed nailing with reaming of the medullary canal. There were several operating surgeons with different levels of experience of the technique. The implants were Küntscher nails (Howmedica, Kiel, Germany) in 8 fractures, Seidel nails (Howmedica, Kiel, Germany) in 75 fractures, St-Pro interlocking nails (Biomet, Warsaw, Indiana, USA) in 39 fractures and UHN interlocking nails (Stratec Medical, Oberdorf, Switzerland) in 4 fractures. Early active postoperative mobilization was encouraged for those treated with interlocking nails, but for other patients rotation of the upper arm was permitted only after three weeks in collar and cuff. The nails were not routinely removed after fracture union.

The patients’ case records and routine radiographs were retrospectively reviewed. The delay between the injury and operation, AO classification (Müller et al. 1990) and localization of the fracture, complications, reoperations and fracture union were assessed by the first author (TF). Distraction of fracture fragments was measured from primary postoperative radiographs. The fracture was considered united when there was evidence of callus bridging the fragments, or blurring of the fracture gap without pain at the site of the fracture in clinical examination. Nonunion was defined as absence of radiological
signs of union, and persistent pain at the site of the fracture with or without progressive osteolysis around the nail and locking screws at six months after the operation. Fourteen patients (12%) were lost to follow-up before fracture union. The patients with pathological fractures were not routinely followed by means of radiographs. Adequate radiographs and patient data to assess fracture union were available for 95 non-pathological fractures.

After a mean follow-up period of 3 (0.5–10) years, shoulder symptoms and function in 67 patients could be assessed by means of a self-administered questionnaire devised by L’Insalata et al. (1997) and in 52 patients, Constant scoring could be used (Constant & Murley 1987). The questionnaire of L’Insalata et al. gives a measure of shoulder joint symptoms and impairment of function perceived by the patient. The Constant score is a combined score, which has a subjective part (pain and function) and an objective part (ROM and strength measurements using a spring balance). The maximum score is 100 points in both scoring systems. The first author (TF) examined the patients and did Constant scoring. The unaffected shoulder served as a control in both scoring systems. Radiography of the humeral shaft was carried out to assess union and possible complications.

### 4.2 IM nailing of pathological fractures of the humeral shaft (II)

The patients in this study (II) consisted of 16 patients with 18 pathological fractures of the humeral shaft treated by IM nailing between the years 1987–1997. The mean age of the patients at operation was 64 (range 34–80) years. There were 4 men and 12 women. The most common underlying malignant disease was breast cancer (5 patients), followed by multiple myeloma (3), renal carcinoma (3), lung cancer (2), thyroid carcinoma (1), angiosarcoma (1) and cancer of unknown origin (2). The mean time interval between diagnosis of malignancy and fracture was 47 (range 1–168) months. Every patient had multiple bone metastases at the time of humeral fracture and 9 patients also had other pathological fractures, five of which had required previous surgical treatment.

The operative technique was antegrade IM nailing with reaming of the medullary canal in all cases. Kuntscher nails were used in two cases, Seidel nails in 9 cases and St-Pro nails in 7 cases. Postoperative irradiation was decided case by case, persistent pain at the site of the lesion being the main indication for irradiation.

The charts and routine AP and lateral radiographs of the patients were evaluated retrospectively. Intra-operative data regarding implants, blood loss, duration of the operation, and intra- and postoperative complications and postoperative irradiation, were assessed from the case records. Union of the fracture was assessed from radiographs among those patients who survived long enough after the operation. Pain relief could be assessed only among those who were alive at the time of the evaluation, using a three-stage scale (poor, satisfactory, good).
4.3 Treatment of nonunion of the humeral shaft after IM nailing

4.3.1 Exchange nailing (III)

This study (III) involved 24 patients with nonunion of the humeral shaft after IM nailing. The patients’ (12 male and 12 female) mean age at the time of injury was 59 years. The definition of nonunion was the same as in study I, failure of union in 6 months.

Thirteen patients were operated upon using antegrade exchange nailing with 1–2 mm over-reaming, during the years 1995–1999. Küntscher nails were used in two cases, Seidel nails in four cases and interlocking nails (St-Pro or UHN) in five patients. In two cases commercial humeral nails were too small in diameter and therefore custom-made interlocking nails or tibial nails were used to allow more reaming and to give more stability. Distraction of the fracture, which was present in 11 cases, was usually compressed manually, but in four cases the compression device of a UHN nail was used. In 6 cases repeated exchange nailing was performed because there were no signs of union during 4–6 months’ follow-up after the operation. Eleven patients either refused any procedures or their general health was considered too poor to allow operative intervention.

Patient data and radiographs were reviewed retrospectively. AO classification of fractures (Müller et al. 1990), site, original nail type and original distraction of the fracture fragments measured from postoperative radiographs were registered. The type of nonunion (atrophic, oligotrophic or hypertrophic) was assessed according to Weber & Cech (1976).

One patient was lost to follow-up, 3 patients had died and 2 patients were unable to complete the questionnaire and shoulder scoring. All other patients were reviewed at the outpatient clinic by an independent physiotherapist after a mean follow-up period of 4.7 (1.0–8.3) years. Shoulder function was assessed using self-administered questionnaires devised by L’Insalata et al. (1997) and by Constant scoring (Constant & Murley 1987). Radiographs were taken to assess fracture union or possible osteolysis around the nail, which was graded as none (−), mild (+), moderate (++) or severe (+++).

4.3.2 Ilizarov’s technique (IV)

The patients in this study (IV) consisted of 7 cases of nonunion of the humeral shaft after IM nailing with, compromised bone quality, treated by Ilizarov’s technique during the years 1998–2000. The case records of the patients were reviewed as regards previous treatment attempts, concomitant illnesses and other factors relevant to nonunion (Table 4). Shoulder joint function was recorded preoperatively and radiographs were examined to assess nonunion type (Weber & Cech 1976) and bone loss (+, ++, ++++) associated with a loose nail.

In the operation the nail was removed without opening the fracture site. Two or three titanium half-pins (5 mm) were inserted both in distal and proximal fragments under
fluoroscopic control. An Ilizarov R frame (Smith & Nephew Richards, Memphis, TN, USA) with half or 5/8 rings was applied. In one case small wires were used in the supracondylar area because of poor bone quality. Compression along the axis of the humerus was started after the second postoperative day; 0.25 mm per day for the first 2 weeks and after this 0.25 mm every second day until signs of bridging callus was seen (Lammens et al. 1998). Mobilization of shoulder and elbow joints was started as tolerated and the patients were encouraged to use the upper extremity normally in everyday tasks. Before removal of the frame, the bars were removed and stability tested. The patients had a custom-made brace for 1–2 months after removal of the frame.

The patients were reviewed after a mean period of 2.6 (2–3) years of follow-up by an independent physiotherapist. One patient had died but all the others were available for review. Self-administered questionnaires, as devised by L’Insalata et al. (1997), and Constant scoring (Constant & Murley 1987), were used to assess shoulder joint function both preoperatively and at follow-up. Radiographs of both humeri were carried out to assess union and alignment.

Fig. 11. Ilizarov frame in a case of nonunion with severe osteolysis after IM nailing.
Table 4. Preoperative data on patients in study IV.

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Sex</th>
<th>Nail</th>
<th>Illnesses</th>
<th>Smoking (cig./day)</th>
<th>Type</th>
<th>IM-nail to Ilizarov (y)</th>
<th>Previous operations</th>
<th>Bone loss</th>
<th>L’Insalata score</th>
<th>Constant score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43</td>
<td>F</td>
<td>UHN</td>
<td>Alcoholism</td>
<td>25</td>
<td>Oligotrophic</td>
<td>2.0</td>
<td>No</td>
<td>++</td>
<td>64</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>46</td>
<td>F</td>
<td>St-pro</td>
<td>Alcoholism</td>
<td>30</td>
<td>Oligotrophic</td>
<td>3.4</td>
<td>Exchange nailing</td>
<td>+</td>
<td>46</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bone graft</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>M</td>
<td>UHN</td>
<td></td>
<td>No</td>
<td>Hypertrophic</td>
<td>2.9</td>
<td>Exchange nailing x2</td>
<td>+++</td>
<td>35</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Plating + bone graft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>29</td>
<td>F</td>
<td>St-pro</td>
<td>Diabetes</td>
<td>15</td>
<td>Oligotrophic</td>
<td>1.7</td>
<td>No</td>
<td>+</td>
<td>65</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Obesity</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>M</td>
<td>Seidel</td>
<td>Personality disorder</td>
<td>30</td>
<td>Hypertrophic</td>
<td>4.9</td>
<td>Drainage</td>
<td>+</td>
<td>33</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Debridement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>54</td>
<td>M</td>
<td>UHN</td>
<td>Schizophrenia</td>
<td>40</td>
<td>Atrophic</td>
<td>1.6</td>
<td>Exchange nailing</td>
<td>+++</td>
<td>69</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>64</td>
<td>M</td>
<td>St-pro</td>
<td>Alcoholism</td>
<td>No</td>
<td>Atrophic</td>
<td>4.0</td>
<td>No</td>
<td>+</td>
<td>27</td>
<td>17</td>
</tr>
</tbody>
</table>

a = antegrade, r = retrograde
4.4 Shoulder joint function after antegrade IM nailing and compression plating of humeral shaft fractures (V)

All Humeral shaft fractures treated by IM nailing or compression plating that had healed without complications or reoperations, except for implant removal, with no significant associated injuries of the ipsi- or contralateral upper extremity were selected in this study (V). The material consisted of 44 patients with IM nailing (20 females, 24 males, mean age 51 (16–75) years) and 29 patients (11 females, 18 males, mean age 41 (range 17–69) years) with plate fixation treated during 1987–2001.

In the IM nailing group 34 patients were operated upon within 10 days of the injury, 6 within 1 month because of malalignment in a brace and 4 patients underwent operation because of delayed union (3 months). A Kuntscher nail (Howmedica, Kiel, Germany) was used in 2 cases, a Seidel nail (Howmedica, Kiel, Germany) in 21, a St-pro nail (Biomet, Warsaw, IN, USA) in 17 and a UHN nail (Stratec Medical, Oberdorf, Switzerland) in 4 cases. IM nailing was performed using an antegrade technique. Early active postoperative mobilization was encouraged among those treated with interlocking nails, but for other patients rotation of the upper arm was permitted only after three weeks in a collar and cuff. The mean follow-up time was 5.5 (2–10) years.

In the DC plate group 27 fractures were operated upon within 10 days of the injury and 2 fractures were operated upon because of delayed union (2 months). Anterolateral or posterior surgical incision was used depending on the location of the fracture. The mean follow-up time in these cases was 6.2 (1–15) years.

The patients were reviewed by an independent physiotherapist. Shoulder joint symptoms and function were assessed using self-administered questionnaires devised by L’Insalata et al. (1997), and Constant scoring (Constant & Murley 1987). Shoulder pain was assessed using a 15 cm visual analogue scale (VAS). Range-of-motion was measured using a goniometer and a Dexter® workstation (Cedaron Medical Inc., Davis, CA, USA). Combined glenohumeral and scapulothoracic flexion, abduction, external rotation and internal rotation were measured. Isometric flexion, abduction and external rotation strength were measured using a Lido® Multi-Joint II isokinetic dynamometer (Loreland Biomedical Inc., West Sacramento, CA, USA). After warming-up, three attempts in each direction were carried out and peak torque was measured. The average of three measurements was used as a final result. The uninjured side was used as a control in scoring systems, ROM and strength measurements.

4.5 Statistical methods

Spearman’s correlation, Mann-Whitney U tests, Wilcoxon signed ranks tests and Chi-square tests were used as statistical methods. A value of $p<0.05$ was considered significant. SPSS v.10.1 (SPSS Inc.) software on a personal computer was used in
statistical calculations and for producing boxplot figures. Data are expressed as mean and range, as appropriate.
5 Results

5.1 IM nailing of humeral shaft fractures (I)

Seventy-four fractures (78%) of 95 united uneventfully. Twenty-one fractures (22%) failed to unite after primary operation. After 20 reoperations on 11 patients, seven fractures united, making the overall nonunion rate 14/95 (15%). Eighteen patients’ postoperative radiographs showed remarkable distraction (Fig. 12) between the fracture fragments (mean 6 mm, range 3 to 10 mm). Distraction of the fracture fragments was significantly associated with nonunion (Mann-Whitney \( U \) test \( p=0.005 \)). There was no significant difference between union rates in fractures that were acute, malaligned in cast, had delayed union or failed ORIF (Chi-square test, \( p=0.81 \)). Age (Mann-Whitney \( U \) test, \( p=0.12 \)), sex, associated injuries, fracture class, localization or combinations of these (Table 4) were not statistically significantly associated with nonunion (Chi square tests, \( p>0.05 \)). The nonunion rates associated with different implants were: Seidel 15/60, St-pro 5/28, UHN 0/3 and Küntscher 1/4. The difference between the implants was not statistically significant (Chi-square test, \( p=0.50 \)).

The mean L’Insalata score for the affected shoulder was 71 (24–100) and for the contralateral shoulder 88 (42–100) (Fig. 13). Constant scores were 66 (16–100) and 86 (50–100) respectively (Fig. 14). The difference between affected and control shoulders was statistically significant in both scoring systems (Wilcoxon signed ranks tests, \( p=0.001 \)). Twenty-six patients regarded the result as good, 16 regarded it as satisfactory, 10 fair and 15 poor. The delay between injury and surgery, and length of follow-up did not correlate with the result in either scoring system (Spearman’s correlation). There was no statistically significant difference between function scores according to implant (Mann-Whitney \( U \) tests, \( p>0.05 \)).

Intraoperative fracture of the greater tuberosity with a remarkable effect on the stability of fixation occurred in two cases and open reduction and wire fixation was needed. Closed reduction was unsuccessful in four cases and open reduction was carried out with supplemental wire fixation in two cases. There were three cases of intraoperative nerve complications. One patient had total radial nerve palsy, one patient radial and ulnar nerve paresis and one patient sensory loss in the lateral upper forearm owing to a lesion.
in the posterior antebrachial cutaneous nerve during insertion of distal locking screws. All primary palsies and one case of iatrogenic radial palsy had resolved by the time of the evaluation. One case of postoperative radial and ulnar nerve paresis resolved only partly. The antebrachial cutaneous nerve lesion was permanent, but caused no problems. Radial nerve explorations were carried out at the time of surgery in five of the ten cases with primary radial nerve paresis. One patient needed reoperation because of a broken drill bit penetrating the glenohumeral joint.

One patient died 2 days after the operation. There were four cases of postoperative infection. Two patients had deep infections after consolidation of the fracture and these were managed with removal of the implant, debridement, antibiotics and a brace. Two patients had superficial infections that were resolved with antibiotics alone. The overall complication rate was 11/126 (9%).

Twenty-three patients needed 35 reoperations for various indications (Table 6). The overall reoperation rate was 35/126 (28%).

**Table 5. Distribution of AO classification of the fractures.**

<table>
<thead>
<tr>
<th>AO class</th>
<th>P 1/3</th>
<th>M 1/3</th>
<th>D1/3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>13 (2)</td>
<td>6</td>
<td>3 (1)</td>
<td>22 (3)</td>
</tr>
<tr>
<td>A2</td>
<td>9</td>
<td>11 (2)</td>
<td>8 (1)</td>
<td>28 (3)</td>
</tr>
<tr>
<td>A3</td>
<td>5</td>
<td>31 (5)</td>
<td>5 (1)</td>
<td>41 (6)</td>
</tr>
<tr>
<td>B1</td>
<td>8 (2)</td>
<td>5 (1)</td>
<td></td>
<td>13 (3)</td>
</tr>
<tr>
<td>B2</td>
<td>4 (3)</td>
<td>6 (2)</td>
<td>1</td>
<td>11 (5)</td>
</tr>
<tr>
<td>B3</td>
<td>1</td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>C1</td>
<td>3</td>
<td>1 (1)</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>C2</td>
<td>1</td>
<td>2</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>44 (7)</td>
<td>65 (11)</td>
<td>17(3)</td>
<td>126 (21)</td>
</tr>
</tbody>
</table>

Nonunion frequency in parenthesis. P1/3 = proximal third, M1/3 = mid-third, D1/3 = distal third of the humerus

**Table 6. Reoperations after IM nailing.**

<table>
<thead>
<tr>
<th>Indication</th>
<th>Procedure</th>
<th>Patients</th>
<th>Number of procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delayed union</td>
<td>Exchange nailing or ORIF + bone graft</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>Shoulder stiffness</td>
<td>Manipulation under anaesthesia</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Subacromial impingement</td>
<td>Acromioplasty</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Infection</td>
<td>Implant removal, debridement</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Implant failure (new trauma) / instrument failure</td>
<td>Exchange nailing</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>23</td>
<td>35</td>
</tr>
</tbody>
</table>
Fig. 12. Postoperative distraction (Seidel nail).
Fig. 13. L’Insalata scores in 67 fractures that united uneventfully, needed reoperation to unite, and remained nonunited (boxplot diagram). The contralateral side served as control. There was a statistically significant difference between shoulders in every group (Wilcoxon signed ranks test, p<0.005).

Fig. 14. Constant scores in 52 fractures that united uneventfully, needed reoperation to unite, and remained nonunited (boxplot diagram). Control values are from the contralateral side. There was a statistically significant difference between shoulders in every group (Wilcoxon signed ranks test, p<0.005).
5.2 IM nailing of pathological fractures of the humeral shaft (II)

The mean duration of the 18 operations was 62 (range 25–95) minutes. The mean intraoperative blood loss during IM nailing was 200 (50–600) ml. Thirteen patients received postoperative irradiation (10–30 Gy). There were no postoperative wound infections. One patient had pneumonia, which was managed with antibiotics. Three fractures united uneventfully, 3 fractures showed nonunion with osteolysis around the nail. Nine patients died before union of the fracture could be assessed, 2 patients had no follow-up and in one case union was radiographically uncertain. In all, 14 patients died. The mean survival time after surgery was 160 (range 39–511) days. Two patients with 3 fractures were alive at the time of evaluation (mean follow-up 10 months) and their pain relief was good for 2 fractures and satisfactory for one.

5.3 Treatment of nonunion after IM nailing of the humeral shaft

5.3.1 Exchange nailing (III)

Three fractures of 13 united after a single exchange nailing and two fractures united after repeated exchange nailing. In one case additional bone grafting was used, resulting in union after repeated exchange nailing. The overall union rate after exchange nailing was six out of 13 fractures. Exchange nailing failed to result in union in 6 cases and one patient died postoperatively (of acute myocardial infarction). The AO classification of the fracture, site, original nail type, type of nonunion or original distraction did not affect the outcome of exchange nailing. Osteolysis around the nail was assessed as mild in 4 cases, moderate in 1 and severe in 5 cases among those patients who were left with nonunion.

The mean shoulder symptom/function scores among those cases showing union were 72 (84% of the control side) in L’Insalata scoring and 58 (67%) in Constant scoring. The mean L’Insalata score was 48 (61%) and the Constant score 39 (45%) in nonunited cases. Two patients regarded the result as good, 8 as fair and 9 regarded it as poor.

5.3.2 Ilizarov’s technique (IV)

Five fractures united and 2 remained nonunited. The time spent in the frame is shown in Table 7 for each patient. Two patients had valgus malalignment (10 and 15 degrees) but the other 3 showed normal alignment compared with the control side. In one case (patient 7) noncompliance of the patient led to severe pin tract infection and osteomyelitis, which necessitated frame removal after one month. The other case (patient 5) of nonunion was an oblique proximal fracture with translation and the frame did not compress the fracture sufficiently.
Both Constant and L’Insalata scores were improved after union, but they were clearly lower than on the control side in most cases (Table 7). In those left with nonunion the scores did not significantly change.

Pin tract infection complicated every case, but it was managed successfully with antibiotics. Two patients needed intravenous antibiotics in hospital, but all others were treated as outpatients with peroral antibiotics. One patient suffered iatrogenic radial nerve lesion, which was caused by a slipping drill bit during pin insertion. Nerve function was resolved completely after 7 months. Five patients needed reoperations. There were pin problems in 3 patients (2 pin breakage, 1 pin loosening), which needed refixation. In one case osteomyelitis of the pin tract necessitated debridement. Refracture after removal of the frame occurred in 2 cases. In one case it occurred one month after removal of the frame (case 1) and was managed with a brace. Another case of refracture (case 3) occurred 6 months after removal of the frame and was the result of a minor trauma. This patient chose not to have a new frame and the refracture was managed with ORIF and a bone graft, with a good result.

Table 7. Postoperative data on patients in study IV.

<table>
<thead>
<tr>
<th>Case</th>
<th>In frame (mo)</th>
<th>Complications</th>
<th>Reoperations</th>
<th>Result</th>
<th>Alignment</th>
<th>L’Insalata</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.9</td>
<td>Radial nerve</td>
<td>Brace</td>
<td>Union</td>
<td>5 valgus</td>
<td>80</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PTI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Refracture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7.3</td>
<td>PTI</td>
<td></td>
<td>Union</td>
<td>10 valgus</td>
<td>75</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>6.8</td>
<td>PTI</td>
<td>Refixation x3</td>
<td>Union</td>
<td>0</td>
<td>37</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pin breakage x3</td>
<td>Refracture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plating+Bone graft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.1</td>
<td>PTI</td>
<td></td>
<td>Union</td>
<td>0</td>
<td>92</td>
<td>77</td>
</tr>
<tr>
<td>5</td>
<td>7.2</td>
<td>PTI</td>
<td>Refixation</td>
<td>Nonunion</td>
<td></td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>7.7</td>
<td>PTI</td>
<td>Refixation</td>
<td>Union</td>
<td>0</td>
<td>Dead</td>
<td>Dead</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pin breakage</td>
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</tr>
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<td></td>
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<td>Refraction</td>
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<td></td>
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</tr>
<tr>
<td>7</td>
<td>1.2</td>
<td>PTI</td>
<td>Revision</td>
<td>Nonunion</td>
<td></td>
<td>41</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Osteomyelitis</td>
<td>IM nail</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PTI = pin tract infection

5.4 Shoulder joint function after antegrade IM nailing and compression plating of humeral shaft fractures (V)

The functional scores and strength parameters for those patients who were operated upon using DC plating were as follows: The mean L’Insalata score was 83 (51–100), which was 88% of that on the control side (mean 94, range 74–100). The mean Constant score was 82 (62–100), which was 91% of that on the control side (mean 90, range 76–100).
Shoulder pain on the injured side was assessed on average as 12 (3–15) on the VA scale. All ROM (Table 8) and strength parameters (Table 9) were statistically significantly lower on the injured side than on the control side ($p=0.001$, Wilcoxon signed rank test).

For those patients who were operated upon using IM nailing the parameters were as follows: The mean L’Insalata score was 79 (38–100), which was 86% of that on the control side (mean 91, range 48–100). The mean Constant score was 75 (41–97), which was 87% of that on the control side (mean 82, range 52–100). Shoulder pain on the injured side was assessed on average as 10 (2–15) on the VA scale. All ROM (Table 8) and strength parameters (Table 9) were statistically significantly lower on the injured side than on the control side ($p=0.001$, Wilcoxon signed rank test).

To allow comparison of IM nailing and plate fixation, the difference between the control and injured side for each parameter was calculated. There was no difference regarding L’Insalata and Constant scores. Although there was an indication that patients with IM nails had more shoulder pain, the difference was not statistically significant (Mann-Whitney $U$ test, $p=0.06$). In ROM parameters, there was a statistically significant difference only in flexion (Mann-Whitney $U$ test, $p=0.04$), and plate fixation tended to be better as regards abduction (Fig. 15). The strength parameters (Fig. 16) were not statistically significantly different.

Table 8. L’Insalata score, Constant score and range-of-motion parameters after IM nailing and DC plating.

<table>
<thead>
<tr>
<th></th>
<th>IM nail</th>
<th>DC plate</th>
<th>difference</th>
<th>IM nail</th>
<th>DC plate</th>
<th>difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture</td>
<td>80</td>
<td>92</td>
<td>12</td>
<td>83</td>
<td>95</td>
<td>12</td>
</tr>
<tr>
<td>Control</td>
<td>75</td>
<td>82</td>
<td>7</td>
<td>82</td>
<td>90</td>
<td>8</td>
</tr>
<tr>
<td>Flexion</td>
<td>145</td>
<td>163</td>
<td>17</td>
<td>164</td>
<td>173</td>
<td>9</td>
</tr>
<tr>
<td>Abduction</td>
<td>134</td>
<td>154</td>
<td>20</td>
<td>156</td>
<td>169</td>
<td>13</td>
</tr>
<tr>
<td>ER</td>
<td>64</td>
<td>70</td>
<td>6</td>
<td>61</td>
<td>69</td>
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<tr>
<td>IR</td>
<td>78</td>
<td>79</td>
<td>1</td>
<td>76</td>
<td>77</td>
<td>2</td>
</tr>
</tbody>
</table>

Statistically significant differences between injured and control sides in all parameters except internal rotation in both the IM nail and DC plate groups (Wilcoxon signed ranks test). Statistically significant difference ($p=0.04$) between IM nail and plate only in flexion (Mann-Whitney $U$ test).
Table 9. Isometric strength (Peak torque, Nm) of the shoulder joint after IM nailing and DC plating of humeral shaft fractures.

<table>
<thead>
<tr>
<th></th>
<th>IM nail</th>
<th>DC plate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fracture</td>
<td>Control</td>
</tr>
<tr>
<td>Flexion</td>
<td>26.2</td>
<td>33.6</td>
</tr>
<tr>
<td>Abduction</td>
<td>25.5</td>
<td>31.6</td>
</tr>
<tr>
<td>ER</td>
<td>18.9</td>
<td>24.0</td>
</tr>
</tbody>
</table>

Statistically significant differences in every parameter between injured and control sides in both the IM nail and DC plate groups (Wilcoxon signed ranks tests). No statistically significant differences between the IM nail and DC plate groups (Mann-Whitney U tests).

Fig. 15. Differences in ROM parameters (degrees) of the shoulder joint between the uninjured and injured side in follow-up examination of IM nailing and DC plating of humeral shaft fractures (boxplot diagram).
Fig. 16. Differences in strength (peak torque, Nm) parameters of the shoulder joint between the uninjured and injured side in follow-up examination of IM nailing and DC plating of humeral shaft fractures (boxplot diagram).


6 Discussion

6.1 Patients and methods

As in most studies of humeral shaft fractures, in this study fracture union, shoulder joint function, and complication and reoperation rates were used as outcome criteria. In a series of radiographs, absence of signs of union 6 months after the injury is generally regarded as nonunion (Mast et al. 1975, Foulk & Szabo 1995, Jupiter & van Deck 1998). Most patients (88%) could be followed long enough to make a valid assessment of fracture union. The number of patients in this study is the largest ever published as regards antegrade IM nailing and this study gives reliable information on bone healing problems.

Restriction in shoulder joint ROM of less than 5–10 degrees in any direction has been used as a criterion of a good functional result in previous studies of humeral shaft fractures (Table 3). Only a few investigators have used shoulder scoring systems (McCormack et al. 2000, Scheerlinck & Handelberg 2002). In this study shoulder joint symptoms and function were measured using self-administered questionnaires and a combined scoring system, which have proven to be valid and reliable in the assessment of shoulder joint function (Constant & Murley 1987, L’Insalata et al. 1997). These scores take into account pain, restriction in ROM in every direction and loss of strength and thus better reveal any problem arising from the shoulder joint than ROM alone. The uninjured side was used as a control in every measurement to compensate for the wide variability of shoulder joint mobility and strength between individuals of different ages (Constant & Murley 1987). It is possible, however that fracture site pain interferes with pain originating from the shoulder joint. Shoulder joint pain often radiates to the deltoid insertion in the proximal humeral shaft and it may be impossible for the patient to tell the difference between these two types of pain. The retrospective setting is a major limitation and a selection bias is possible, because 30% of the patients were lost to follow-up before the assessment of shoulder joint scores.

Isometric strength measurements are valid and reproducible in shoulder joint strength measurement (Kuhlman et al. 1992). Similar methods have been used to assess outcome after rotator cuff impingement surgery (Gore et al. 1986, Hyvönen et al. 2000). The
uninjured side acted as a control owing to great individual variation of shoulder muscle strength (Ivey et al. 1985). Hand dominance in young active sportsmen should be taken into account when assessing shoulder muscle strength (Chi-hung et al. 1995). However, hand dominance has only a minor effect on shoulder muscle strength in the normal population and the uninjured side can be used as a control (Ivey et al. 1985, Murray et al. 1985).

The small number of patients in this and previous studies on pathological fractures, exchange nailing and Ilizarov’s technique makes it difficult to draw any statistical conclusions. These conditions are rare and it is difficult to organize multicentre studies because only a few surgeons are familiar with these techniques.

The material in this study was relatively heterogeneous. Besides acute fractures, many patients were treated because of failed nonoperative treatment, delayed union or nonunion. All fractures were included, however, to give an overview of the method. As a result of having several operating surgeons and four nail types in use, a learning curve effect may have interfered with the true performance of the implants.

In the study in which we compared shoulder muscle recovery after IM nailing and DC plating (V), the purpose was to discover, whether antegrade IM nailing even if carried out properly is the cause of shoulder joint impairment. Therefore, patients with complications and healing problems were excluded. Given the high incidence of nonunion in the first study, it would have been unethical to conduct a prospective study. The nonrandomized setting may have caused a selection bias, because the surgeon on duty decided the method. Older patients and patients with more severe comminution of the fracture are more probably operated upon using IM nailing than younger patients with good bone quality. In addition distal fractures not suitable for IM nailing may be overrepresented in DC plating. The effect of this selection bias would be that patients treated by means of DC plating would probably heal better than those treated by means of IM nailing. However, in this study shoulder joint function after DC plating was clearly worse than expected and the role of selection bias was probably minor.

Despite some methodological limitations, this study can give useful information and solutions to handling of specific problems associated with antegrade IM nailing of humeral shaft fractures.

### 6.2 IM nailing of humeral shaft fractures (I)

The results of antegrade IM nailing as regards union rate and shoulder joint function are very controversial. Results in published retrospective follow-up studies are usually worse than those after nonoperative treatment or DC plate fixation (Tables 1–3). The results of comparative studies, however, have not shown a significant difference in outcome after IM nailing compared with other methods (Wallny et al. 1997b, Lin 1998, Chapman et al. 2000, McCormack et al. 2000).

In the present study antegrade IM nailing resulted in nonunion in a high percentage (22%) of cases, shoulder joint function was severely impaired in 37% of the patients and the reoperation rate was high (28%). Distraction of the fracture fragments was associated with nonunion. This has not been previously recognized as a problem after IM nailing,
although it has been recognized as a major cause of nonunion in nonoperative treatment (Sarmiento et al. 1977, Ulrich 1996a, Jupiter & van Deck 1998, Sarmiento et al. 2001, Koch et al. 2002). Küntscher originally proposed that distraction of the fracture after IM nailing is filled by callus if the extremity is used forcefully (Küntscher 1962). The humerus is a hanging bone and gravity tends to distract fracture fragments. In the lower extremity in cases of delayed union, dynamization of the nail with weight bearing tends to close fracture distraction and this may stimulate bone healing (Wu & Shih 1993). Several surgeons of different levels of experience had operated on the present fractures and distraction may have been a simple technical error. The medullary canal begins narrowing about 3 cm above the olecranon fossa and this may cause jamming of the nail tip and contribute to distraction at the site of the fracture during nailing (Riemer et al. 1994, Rupp et al. 1996). To avoid distraction of the fragments, a meticulous operative technique must be used. The retrograde technique tends to compress rather than distract the fragments and this may partly explain the better union rates reported with this technique (Rommens et al. 1995, Blum et al. 1997, Lin et al. 1997). More recently Lin et al. 2003a discussed the role of fracture distraction and regarded it as a major factor causing nonunion.

The source of shoulder function impairment after antegrade humeral intramedullary nailing is unclear. Proximal migration of Küntscher and Seidel- nails is well recorded and may cause subacromial impingement in up to 60% of patients (Foster et al. 1985, Robinson et al. 1992). Migration is not a problem with interlocking nails. In this series, however, there was no significant difference in shoulder function impairment as regards interlocking and other nails. According to clinical experience, shoulder pain after antegrade intramedullary nailing is not that of a typical subacromial impingement syndrome. According to Ikpeme (1994), proximal locking screws protruding into the deltoid muscle may be a major source of shoulder pain. Old age has been recognized as a risk factor of shoulder stiffness after nonoperative treatment (Koch et al. 2002), but in this study age did not correlate to shoulder scores. The role of underlying rotator cuff disease on postoperative shoulder problems has not been studied.

The high incidence of nonunion among the patients partially explains the poor overall functional result. In addition repeated operations resulted in worse function than in those that healed after the first operation. However, the majority of patients whose fracture healed uneventfully had shoulder joint impairment.

The role of IM nailing in the treatment of humeral shaft fractures is controversial. On the basis of the present study and current literature it is evident that IM nailing has no advantage over nonoperative treatment (Mast et al. 1975, Sarmiento et al. 1977, Foulk & Szabo 1995, Koch et al. 2002). The indications for IM nailing of humeral shaft fractures may be exceptional, such as when other treatment methods are likely to fail, as in comminuted or segmental fractures, or when rapid fracture stabilization is necessary in those critically injured (Sarmiento et al. 2001, Lin & Hou 2003).
6.3 IM nailing of pathological fractures of the humeral shaft (II)

In diaphyseal lesions, intramedullary nailing is a rapid procedure with little intra-operative bleeding, morbidity or complications and it appears to give satisfactory pain relief. Because of short life expectancy, nonunion is not a significant problem. Even in cases of nonunion, the intramedullary device can give sufficient stability for pain relief and satisfactory function. Interlocked nails, which provide rotational stability and do not migrate, are preferable to unlocked implants. However, in cases of metastasis of the humeral shaft due to a slowly progressing disease, close follow-up is needed to treat possible nonunion early.

Most pathological fractures of the humeral shaft can be nailed using a closed technique. Curettage and PMMA fill of the lesion is not needed, which shortens the operative time and reduces the risk of bleeding and radial nerve palsy (Dijkstra et al. 1996).

The mean survival time after pathological humeral fracture in our series was 5 months, which is line with previous reports (Sim et al. 1974, Harrington et al. 1976, Flemming & Beals 1986, Lancaster et al. 1988, Vail & Harrelson 1991, Redmond et al. 1996). There was no mortality associated with the operation and the results support the idea that survival after pathological fracture is determined by the nature of the primary tumour, not the treatment of the fracture (Vail & Harrelson 1991). Advanced age of a patient is not a contraindication, if their general condition permits operative intervention (Grabbe et al. 1996).

The role of postoperative irradiation is controversial (Bonarigo & Rubin 1967, Harrington et al. 1976). In this study postoperative irradiation was not associated with any problems, but the three cases of nonunion occurred in irradiated patients.

Antegrade IM nailing is a rapid, safe and effective method for treating pathological fractures of the humeral shaft.

6.4 Treatment of nonunion after IM nailing of humeral shaft fractures

6.4.1 Exchange nailing (III)

The results of exchange nailing of humeral shaft fractures in this study support those reported by other authors (Robinson et al. 1992, McKee et al. 1996b). The union rate of 48% is remarkably lower than the reported rate of 92–100% in exchange nailing of femoral and tibial fractures (Webb et al. 1986, Court-Brown et al. 1994, Templeman et al. 1995, Furlong et al. 1999, Wu et al. 1999, Hak et al. 2000).

The reason why exchange nailing works poorly in the humerus is not well understood. Riemer et al. (1994) pointed out that the medullary canal of the humerus is different to that of the femur and tibia. The endosteal bone is hard and reaming possibly does not have the same effect as in the lower extremity (Riemer 1996). In cases of bone defects,
exchange nailing fails to produce union in tibial fractures (Court-Brown et al. 1994). In the humerus, antegrade nailing may easily distract fracture fragments, because the medullary cavity narrows above the olecranon fossa (Riemer et al. 1994, Rupp et al. 1996). In our series there was measurable distraction in 11 fractures. Weight-bearing after exchange nailing without interlocking in the lower extremity tends to eliminate distraction between the fracture fragments, but this does not apply to the upper extremity (Court-Brown et al. 1994). In this study fracture distraction was eliminated in 4 cases by using a compression device during exchange nailing. Union was achieved in only one of these cases, suggesting that factors other than fracture distraction may play a significant role. Recently Lin et al. (2003b) reported good results using exchange nailing with autologous bone grafting in 23 patients. They also used supplementary interfragmentary wiring to eliminate fracture gaps and all fractures united. This technique, however, is not true exchange nailing. Bone grafting may be responsible for fracture union and a larger IM nail is for stability only. Bone grafting should be done early before osteolysis develops, because stability may be difficult to achieve by means of IM nails later. Cancellous bone grafting without exchange nailing in cases of bone defects is also effective in cases of nonunion after IM nailing of the tibia (Court-Brown et al. 1994).

Bone healing after exchange nailing of tibial and femoral nonunion is mainly periosteal (Court-Brown et al. 1994, Furlong et al. 1999, Wu et al. 1999). Reaming, though interfering with endosteal circulation, is considered to result in an increase of blood supply to the bone through an increase in periosteal blood flow (Reichert et al. 1995). Exchange nailing of the humeral shaft did not result in typical periosteal callus as seen in exchange nailing of tibial nonunion. Intramedullary nailing or reaming of the humerus may interfere with endosteal blood supply without an increase in periosteal blood flow, and this could explain the high nonunion rate after IM nailing of acute humeral fractures, and the poor results of exchange nailing.

Poor results of exchange nailing, as demonstrated in this study and previous studies, does not support its clinical use (Robinson et al. 1992, McKee et al. 1996b, Farragos et al. 1999). Early ORIF with autologous bone grafting may be the best way to treat these problems (Jupiter & van Deck 1998, Farragos et al. 1999, Pugh & McKee 2003).

Our results suggest that shoulder joint function does not recover to normal after treatment of nonunion. Permanent nonunion leaves the patient with severe disability. This is in contrast to early reports on IM nailing suggesting that patients with nonunion do well because the nail stabilizes the bone anyway (Christensen 1976). If the nail is left in the medullary cavity in a nonunited fracture, severe osteolysis will eventually take place. It jeopardizes cortical integrity. There will be a risk of secondary fractures and their treatment will be very difficult.

### 6.4.2 Ilizarov’s technique (IV)

Ilizarov’s technique was successful in 5 out of 7 cases. Shoulder function was usually restored to a satisfactory level. This was achieved at the cost of several minor complications, some reoperations and inconvenient time spent in a frame. The results confirm that nonunion after intramedullary nailing with compromised bone quality is a
very difficult problem to deal with (McKee et al. 1996b, Farragos et al. 1999, Lin et al. 2003a). Our patients were particularly difficult as regards their concomitant illnesses. Heavy smoking, psychiatric disturbances and alcoholism were common problems. However, the patients tolerated the fixation device relatively well; some were unable to take care of the pin sites by themselves, which resulted in device removal and deep infection in one case. Pin tract infections are inevitable in these cases, but other complications are technique-related. Two refractures as a result of minimal trauma after removal of the fixation device were probably associated with poor bone stock and/or too early removal of the frame.

Ilizarov’s technique worked well even in severely compromised bone in this series. Pins directed perpendicularly to each other offer good stability in two planes. A ring fixator allows pins to be inserted independently of each other in areas of best bone quality. In only one case did the pins loosen, necessitating reoperation. In other cases pins broke rather than becoming loose, indicating a good purchase even in cases of compromised bone quality.

The technique used in this study was the same as that reported by Lammens et al. (1998). They also experienced refractures after removal of the frame, but they were managed by means of a new frame. Refractures may be associated with poor bone quality. Patel et al. (1999) and Menon et al. (2002) did not remove the nail and this technique may help to keep better alignment during compression. In addition retaining the nail might prevent early refractures and give time for the bone to become stronger.

Ilizarov’s technique, although associated with several problems, is a valuable option to treat these often very difficult cases.

6.5 Shoulder joint function after IM nailing and compression plating of humeral shaft fractures (V)

Although IM nailing did not appear to be as good as DC plating there were no statistically significant differences in shoulder joint pain, functional scores or isometric strength parameters between patients with IM nailing and those with plate fixation. In ROM assessment only flexion was statistically significantly different (better after plating compared with IM nailing). However, the difference was only 9 degrees and not clinically relevant. ROM and strength of the injured shoulder did not return to normal even after plate fixation, suggesting that shoulder joint impairment is not purely a result of the antegrade nailing technique. This is the only study in which isometric shoulder muscle recovery after humeral shaft fractures has been reported.

As already mentioned, follow-up studies and comparative studies give controversial results of the effect of antegrade IM nailing on shoulder joint function. The results of this study are in line with those of previous comparative studies of antegrade IM nailing and DC plate fixation, which have not demonstrated significant differences in shoulder joint function (Lin 1998, Chapman et al. 2000, McCormack et al. 2000, Meekers & Broos 2002). Antegrade nailing, when carried out properly, is probably not the only cause of shoulder joint impairment. The results of this study support the idea that probably all treatment methods of humeral shaft fractures are associated with shoulder joint
impairment, which may be a result of initial injury or postoperative pain (Lin 1998, Riemer 1996). Nail insertion through the rotator cuff or nail insertion site pain may worsen the effect of these factors and make postoperative rehabilitation more difficult. Subacromial scarring might partly explain the restriction in flexion in our material. Impairments after humeral shaft fractures may be multifactorial as in femoral fractures (Kapp et al. 2000).

Shoulder joint function after DC plating has received little attention. Previous studies have not addressed the problem of shoulder joint ROM and strength not recovering completely. The reason is not known. An underlying rotator cuff tear may cause prolonged shoulder pain and loss of ROM after the initial injury. A new tear of the rotator cuff may also occur concomitantly with the fracture. Muscle damage when a surgical incision is made should not interfere with shoulder joint, but may cause restriction in elbow ROM and strength. In the femur something similar has been shown by Finsen et al. (1993), who compared quadriceps and hamstring muscle function after plated and nailed femoral shaft fractures. Hamstring strength was reduced in both groups compared with the non-affected side. Quadriceps strength, however, was reduced by 12% only in plated cases (Finsen et al. 1993).

Intramedullary nailing of femoral and especially tibial fractures can result in some pain at the insertion site of the nail and reduced strength of adjacent joints (Biyani et al. 1993, Court-Brown et al. 1997, Dodenhoff et al. 1997, Kapp et al. 1999, Toivanen et al. 2002). Kapp et al. (1999) reported long-term reduction in quadriceps strength after IM nailing of femoral shaft fractures, but hip flexion and abduction power were not affected and hip pain was not noted. Biyani et al. (1993) noted that heterotopic ossification is associated with hip pain and abduction weakness. Up to 56% of patients note some degree of chronic anterior knee pain after IM nailing of tibial fractures (Court Brown et al. 1997). The type of approach, whether transtendinous or paratendinous insertion of the nail, does not affect the prevalence of pain (Toivanen et al. 2002). Toivanen et al. (2002) also noted reduced quadriceps strength as a result of insertion site morbidity.

It seems inevitable that IM nailing of any long bone is associated with some insertion site morbidity, but the shoulder joint may be especially slow to recover after antegrade insertion of an IM nail (Riemer 1996, Farragos et al. 1999).
7 Conclusions

The following conclusions can be drawn from the present study:

1. Antegrade intramedullary nailing of humeral shaft fractures may result in nonunion, and impairment of shoulder function. The nonunion rate is significantly higher than previously reported rates after nonoperative treatment and plate fixation. Distraction of the fracture may be a major cause of nonunion.

2. Antegrade intramedullary nailing is a rapid, safe and effective method for treating pathological fractures of the humeral shaft.

3. Exchange nailing for nonunion after IM nailing of the humerus is ineffective and other methods should be used to treat this condition. Permanent nonunion after antegrade intramedullary nailing of the humeral shaft leaves the patient with severely impaired shoulder joint function and bone integrity is jeopardized by a loose nail.

4. Ilizarov’s technique is a valuable option to treat difficult cases of nonunion after IM nailing associated with bone loss due to a loose nail.

5. Shoulder joint symptoms, range-of-motion and isometric strength do not recover to normal after uncomplicated antegrade IM nailing or plate fixation of humeral shaft fractures. There is no significant difference between IM nailing and plating, suggesting that rotator cuff damage during nail insertion is not the main reason for shoulder joint problems.
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