QUALITY OF TREATMENT
OF SUPRACONDYLAR HUMERUS
FRACTURES IN CHILDREN

Noora Tuomilehto

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ABSTRACT

Childhood fractures are common: it is estimated that two out of five boys and one out of three girls sustain at least one fracture before the age of 16. The humerus is the second most common fracture location after the radius. Supracondylar humerus fractures (SCHFs) are the most frequent distal humerus fractures, followed by lateral condyle and medial epicondyle fractures. Displaced SCHF is commonly treated with internal fixation, and it is the most common operatively treated fracture type in children. Postoperative follow-up with radiographs 1–2 weeks after surgery and at pin removal is generally carried out without evidence of an effect on treatment. Vascular injuries are rare. Displaced SCHFs are associated with the highest risk of nerve injury among pediatric fractures. Most injuries are caused by the trauma itself, but an incidence of iatrogenic injuries related to pin fixation of up to 4% has been reported. The most well-known complication of SCHF is varus (gun-stock) deformity, which is mostly considered a cosmetic issue. In Finland, treatment complications are compensated for by the Patient Insurance Centre (PIC). Long-term outcome of displaced SCHF has not been well documented.

The alignment of a distal humerus fracture is assessed in radiographs from the Baumann angle (BA) and the lateral capitellohumeral angle (LCHA), and also by using the anterior humeral line (AHL) crossing point with the ossification center of the capitellum. The subjective outcome is usually assessed with validated scoring systems and the objective outcome according to Flynn’s criteria.

In this retrospective study we analyzed data from children treated for SCHF with manipulation under anesthesia and pin fixation in the Children’s Hospital, Helsinki. Data were collected from patient records and all available radiographs were analyzed by a pediatric radiologist and an orthopedic registrar. Treatment injuries were evaluated using patient compensation claims from the PIC.

Two hundred (200) consecutive children with pin-fixed SCHF between June 2002 and March 2007 were included in our study concerning the postponement of operative treatment of SCHF to office hours. The first 100 patients were treated before November 2004. After this, night-time operations (midnight to 7.00 a.m.) were permitted only for patients with compromised distal blood circulation. The purpose of this study was to assess whether the quality of operative treatment can be improved by using a better standard of reduction and pin fixation. Evidenced decrease in operating room time without a change in complication rate or admission duration in days decreased the overall treatment expenses. No statistical difference in the quality of reduction or pin fixation was observed, even though the acute reoperation rate decreased from three to zero, the quality of pin fixation improved.
(the radiologically stable pin fixation rate increased from 42% to 55%) and partial loss of reduction decreased from 4% to 1% after the new regulation was introduced.

One hundred and sixty-seven (167) children from 2002 to 2006 and 97 from 2012 to 2014 were included in our study evaluating the significance of postoperative radiographic examinations for treatment after pin fixation of SCHF. We also assessed the clinical usefulness of Baumann and LCH angles in defining fracture alignment. Four hundred and twenty-six (426) postoperative and 90 stored intraoperative fluoroscopic images were analyzed. We found the Baumann angle to have little predictive value regarding outcome: even though an abnormal Baumann angle was measured in almost one-third of our patients’ elbows after pin fixation, no reoperations were performed and only one corrective osteotomy was performed for gun-stock deformity. The AHL and its relation to the bony capitellum were almost always assessable (98%), and its correlation with clinical results was far better than that of the LCHA (with the AHL passing the capitellum in 84% vs normal LCHA in 40%), with no corrective osteotomies performed for sagittal plane malunions. Despite the fact that one-third of fractures were fixed with one or no pins crossing both fracture fragments, reduction was compromised in only 10 cases (the findings did not have an effect on the treatment or lead to reoperation). We concluded that reduction of a displaced SCHF is acceptable when the AHL crosses the ossification of the capitellum in the sagittal plane, and when the carrying angle (CA) is restored to within 10° of the contralateral side. Stability of pin fixation should be tested intraoperatively and recorded. Pins can be safely removed after 3–4 weeks. The routine use of postoperative radiographs does not appear to be justified.

The quality of treatment of distal humerus fractures in Finland was assessed by analyzing all compensation claims filed with the PIC concerning distal humerus fractures in children under 17 years of age between 1990 and 2010. An independent expert retrospectively blindly analyzed all decisions made by the PIC. A medical advisor working for the PIC also re-evaluated the cases without knowing the decisions made by the PIC. During the study period, 133 compensation claims by 117 children (118 fractures) were filed. Nationwide, the risk of having a compensated treatment complication in connection with a pediatric distal humerus fracture was 1%. The rate of compensated treatment complication in patients varied between treatment institutions of different levels, as follows: 0.8% in university hospitals; 1.2% in central hospitals; 2.3% in district hospitals; 10% in private clinics and 13.6% in healthcare centers. There was a threefold difference in the treatment complication rate between university hospitals having the lowest and highest risk (0.5–1.5%). On the basis of the re-evaluation of all compensation claims, a total of 90 patients experienced treatment complications (59 supracondylar, 12 lateral condylar, nine medial epicondylar, five T-type, three lateral epicondylar, and two medial condylar fractures). Delayed treatment concerned 29/90 patients (including nine patients with a missed diagnosis). Nerve injuries turned out to be the third-largest treatment complication.
complication (18/90 patients). Deformity was the most notable complication (53/90 patients). The independent expert and the PIC medical advisor disagreed with the decisions made by the PIC in 13% (15/118) of the cases. In our opinion, compensation claims concerning distal humeral fractures in children should be evaluated by medical advisors with experience in pediatric orthopedics.

Two hundred and ten (210) domestic pin-fixed children who sustained a SCHF between 2002 and 2006 were invited to participate in our subjective and objective long-term outcome study (mean follow-up time of nine years). Subjective outcome was assessed with a questionnaire regarding the appearance, function and pain (scale 0–10) of the fractured elbow, and regarding the symmetry of range of motion (ROM) and carrying angle (CA) of their elbows. The mean subjective score for appearance was 8.7 (range 2–10) and for function 9.0 (range 2–10) according to the 168 answered questionnaires. Elbow pain, either at rest or in motion or both, was reported by 14% of children: it was more common in children with nerve injury. The subjective assessment of elbow ROM and CA of the control visit patients proved to be unreliable when the asymmetry was ≤10° but half as often recognized when the asymmetry was >10°. According to Flynn’s criteria, the objective outcome was good or excellent in 60/65 of the control visit patients in relation to ROM and in 56/65 in relation to CA. Elbow flexion deficit exceeding 10° correlated with lower subjective functional outcome and CA varus asymmetry exceeding 10° correlated with decreased subjective cosmetic and functional outcomes. Subjective cosmetic outcome correlated negatively with open reduction in our study, which was most likely due to the scar. The rate of Volkmann’s contracture was zero and the risk of deep infection and permanent treatment-related nerve complications was low (<1%).

In our long-term outcome study, the risk of complication was higher and the long-term outcome was poorer in patients operated on by registrars compared to those operated on by consultants, although the differences did not reach statistical significance. In our opinion, operative treatment of pediatric distal humeral fractures should be performed by an experienced surgeon, and operative treatment of pediatric distal humeral fractures could be centralized in the five university hospitals in Finland.
LYHENNELMÄ


Olkaluun alaosan murtuman asentoa on tyypillisesti arvioitu röntgenkuvista Baumannin kulman, lateraalisen capitellohumeralikulman ja etummaisen (anteriorisen) olkaluun linjan sekä capitellumin luutumistumakkeen leikkauspisteen mukaan. Subjektiivinen pitkäaikaista-tulos on yleensä arvioitu valditoitua potilaskyselyitä apuna käyttäen ja objektiivinen pitkäaikaista-tulos Flynnin kriteeristöön mukaisesti.


Kaksi sataa (200) kesäkuusta 2002 maaliskuuhun 2007 perijälkeen piikki-kiinnityksellä hoidettua olkaluun suprakondylaarimurtumapotilasta kutsuttiin osallistumaan tutkimukseen, joka koski leikkaushoidon viivästämistä virka-aiakan. Ensimmäiset sata (100) potilasta oli hoidettu ennen vuoden 2004 marraskuuta, jonka jälkeen yöläiskinainen (klo 24–07) leikkausstoiminta sallittiin vain potilaille, joilla oli murtumaan liittyvää ylimääräisen verenkiertohäiriön. Tämän osatutkimuksen tarkoitus oli selvittää, onko leikkaushoidon laatua mahdollisuus parantaa murtumareduktion ja piikki-kiinnityksen tasoa verraten. Käytetyn leikkaushoidon väheneminen ilman
komplikaatioiden tai sairaalassa vietettyjen päivien määrän nousua pienensi hoidon kokonaiskustannuksia. Vaikka tilastollisesti merkittävää muutosta murtumareduktiossa tai piikkikiinnityksessä ei voitu osoittaa, akuuttien uusintaleikkausten määrä laski kolmesta nollaan, piikkikiinnityksen laatu parani (radiologisesti stabilien piikkikiinnitysten osuus nousi 42%:sta 55%:iin) ja osittainen asennon pettäminen laski neljästä (4) prosentista yhteen (1) prosenttiin uuden leikkaussaliaikataulutuksen käyttöönoton jälkeen.


Olkaluun alaosan murtumien hoidon laatua lapsilla Suomessa arvioitiin analysoimalla Potilasvakuutuskeskuksesta kerättyt alle 17-vuotiaita potilaita koskevat vahinkoilmoitukset vuosilta 1990–2010. Vahinkoilmoitukset analysoitiin sekä itsenäisen asiantuntijan että potilasvakuutuskeskukselle työskentelevän asiantuntijan toimesta heidän tietämättä potilasvakuutuskeskuksen päättöistä. Tutkimusaikana kirjattiin 133 vahinkoilmoitusta 117 lapselta (118 murtumaa). Kansallisella tasolla korvattavien potilasvahinkojen määrä oli 1% hoidetuista murtumista, ja osuus vaihteli hoitolaitoksen mukaan seuraavasti: 0,8% yliopistosairaaloissa, 1,2% keskussairaaloissa, 2,3% alueen sairaaloissa, 10% yksityisklinikoissa ja 13,6% terveyskeskuksissa. Ero yliopistoklinikoiden suurimman ja matalimman hoitovirhemäärän

LYHENELMÄ
välillä oli kolminkertainen (0,5%–1,5%). Asiantuntijoiden uudelleenarvion jälkeen 90 potilaalla todettiin hoitovirhe (59 suprakondylaarimurtumaa, 12 lateraalikon-
dylin murtumaa, yhdeksän mediaalisen epikondyylin murtumaa, viisi T-tyyppin murtumaa, kolme lateraalisen epikondyylin murtumaa ja kaksi mediaalikondylin murtumaa). 90 potilaan otokseessa viivästynyt hoito koski 29 potilasta, mukaan lukien yhdeksän ei-diagnoositoa murtumaa. Hermovamma oli kolmanneksi yleisin syy hoitovirheeseen (18 potilasta). Virheenä oli kalkista yleisin hoitovirhe (53 potilas-
ta). Itsenäinen asiantuntija ja potilasvakautukkeskuselle työskentelevä asiantuntija olivat erimielisiä potilasvakautukkeskuksen päätöksen kanssa 13% tapauksista (15 tapausta 118 tapauksen otannassa). Mielestämme hoitovirheimoitukset tulisi arvioida sellaisen asiantuntijan toimesta, jolla on erityisosaamista lastenortopediasta.

Kaksisataakymmenen (210) Suomessa asuvaa piikkikiinnityksellä hoidettua suprakondylaarimurtumapotilasta vuosilta 2002–2006 kutsuttiin osallistumaan subjektiivistä ja objektiivistä pitkäaikaistulosta koskevaan osatutkimukseen, potilaiden seuranta-aika oli keskimäärin yhteensä vuotta. Subjektiivinen pitkäaikaistulos selvitettiin murtuneen kyynärpään ulkonäköä, toimintaa ja kipua (asteikko 0–10) ja kyynärpäiden liikelaajuuden sekä kantokulman symmetriaa tarkastelevalla ky-
selytutkimuksella. Yhteensä 168 vastauksen joukossa keskimääräinen subjektiivi-
nen arvosana ulkonäölle oli 8.7 (vaihteluväli 2–10) ja toiminnalle 9.0 (vaihteluväli 2–10). 14% osallistujista raportoi kyynärpään kipua joko levossa tai liikkeessä ja se oli yleisempää hermovammapotilailla. Kliiniiseen kontrolliin osallistui 65 lasta. Potilaaiden oma arvio kyynärpäiden liikelaajuksista ja kantokulmista osoittautui epäluotettavaksi kontrollikäyntipotilailla ≤10° epäsymmetrioissa, mutta puolet luotettavimmaksi >10° epäsymmetrioissa. Objektiivinen lopputulos oli hyvä tai erinomainen 60/65 potilaasta liikelaajuuden ja 56/65 potilaasta kantokulman suhteen Flynnin kriteeristöön mukaisesti. Kyynäränvellen yli 10° liikerajoitus korreloi huonomman subjektiivisen funktionaalisen lopputuloksen kanssa ja kantokulman yli 10° epäsymmetria huonomman funktionaalisen sekä kosmeettisen lopputulok-
sen kanssa. Subjektiivinen kosmeetinen lopputulos korreloitati negatiivisesti avoimen murtumareduktion kanssa, mikä todennäköisesti liittyi leikkauksenjälkeiseen ar-
peen. Volkmannin iskeeminen kontrakturan esiintyvyys oli nolla ja riski syvään infektoon tai pysyvään hoidosta johtuvaan hermovammaan matala (<1%).

Pitkäaikaistuloksia käsittelevässä tutkimuksessamme murtumakompli-
kaatioihin riski oli suurempi ja subjektiivinen pitkäaikaistulos huonompi potilaila,

jotka oli operoinut erikoistuva lääkäri verraten potilaisiin, jotka oli operoinut eri-
koislääkäri, vaikkakaan ero ei ollut tilastollisesti merkittävä. Mielestämme olkaluun alaosan murtumien leikkaushoito lapsilla tulisi suorittaa kokeneen kirurgin toimesta

ta opastuksella, ja näiden murtumien leikkaushoito voitaisiin keskittää maamme

viiteen yliopistoklinikkaan.
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LIST OF ORIGINAL PUBLICATIONS

This doctoral dissertation is based on the following publications:


The publications are referred to in the text by their Roman numerals. These articles were reprinted with the permission of the copyright holders. In addition, some previously unpublished data are presented.

As my own contribution, I participated in the study design and the application for a research permit from the Children’s Hospital, Helsinki and The Ethics Board of Helsinki University Central Hospital. I was responsible for the collection and interpretation of the data in studies I–IV. I also analyzed all radiographs. In study IV, I met all control visit patients and performed the clinical examination.
## ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AHL</td>
<td>anterior humeral line</td>
</tr>
<tr>
<td>AIN</td>
<td>anterior interosseous nerve</td>
</tr>
<tr>
<td>AVN</td>
<td>avascular necrosis</td>
</tr>
<tr>
<td>BA</td>
<td>Baumann angle</td>
</tr>
<tr>
<td>CA</td>
<td>carrying angle</td>
</tr>
<tr>
<td>CT</td>
<td>computed tomography</td>
</tr>
<tr>
<td>HILMO</td>
<td>Care Register for Health Care</td>
</tr>
<tr>
<td>K wire</td>
<td>Kirschner wire</td>
</tr>
<tr>
<td>LCHA</td>
<td>lateral capitellohumeral angle</td>
</tr>
<tr>
<td>LOR</td>
<td>loss of reduction</td>
</tr>
<tr>
<td>MRI</td>
<td>magnetic resonance imaging</td>
</tr>
<tr>
<td>PIC</td>
<td>Patient Insurance Centre</td>
</tr>
<tr>
<td>PIM</td>
<td>pain in motion</td>
</tr>
<tr>
<td>PIN</td>
<td>posterior interosseous nerve</td>
</tr>
<tr>
<td>PAR</td>
<td>pain at rest</td>
</tr>
<tr>
<td>ROM</td>
<td>range of movement</td>
</tr>
<tr>
<td>SCHF</td>
<td>supracondylar humerus fracture</td>
</tr>
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INTRODUCTION

Two-thirds of children’s fractures occur in the upper extremity. The humerus is the second most common fracture location after the radius. Supracondylar humerus fractures (SCHFs) are the most common distal humerus fractures, followed by lateral condyle and medial epicondyle fractures. Medial condyle and lateral epicondyle fractures are rare.

Displaced SCHF is commonly treated with internal fixation, and it is the most common operatively treated fracture type in children. Reduction and pin fixation of distal humerus fractures in children can be technically challenging, especially in inexperienced hands. Consultant assistance, for both diagnostic purposes and operative treatment, is usually more guaranteed during office hours.

The quality of the reduction of SCHF has traditionally been assessed in radiographs by evaluating frontal alignment with respect to the Baumann angle (BA) and by evaluating sagittal alignment with respect to the anterior humeral line (AHL) crossing point with the capitellum or the lateral capitellohumeral angle (LCHA).

Postoperative radiographic follow-up with radiographs 1–2 weeks after surgery and at pin removal is generally used without evidence of an effect on treatment.

Vascular injuries are a rarity, even though up to one in seven children with dislocated SCHF has compromised blood circulation at admission to hospital. Displaced SCHF is associated with the highest risk of nerve injury among pediatric fractures. Most injuries are caused by the trauma itself, but an incidence of iatrogenic injuries related to pin fixation of up to 4% has been reported. Postoperative infections are mostly superficial and heal with pin removal and oral antibiotics. The most well-known complication of SCHF is varus (gun-stock) deformity, which is mostly considered a cosmetic problem, even though functional limitations and a risk of lateral condyle fractures have been reported. In Finland, treatment complications are compensated for by the Patient Insurance Centre (PIC).

Long-term outcome of displaced SCHF has not been well documented. Objective long-term outcome is usually assessed using Flynn’s criteria and subjective outcome is assessed with validated outcome measures.

Our objective is to improve the treatment of pin-fixed SCHF in children by formulating guidance for pin fixation of SCHF based on the conclusion of our study. The purpose of this study is to assess whether operative treatment of SCHF can safely be postponed to office hours with improved fracture reduction and pin fixation. The objective is also to assess the clinical significance of postoperative radiographic follow-up and to determine whether primary radiographic parameters have prognostic value for long-term outcome. Our goal is to identify the most
common reasons for compensated treatment injuries in pediatric distal humerus fractures and to assess the quality of treatment of these fractures in Finland. We also want to determine the objective and subjective long-term outcomes in operatively treated SCHF in the Children’s Hospital, Helsinki.
2 REVIEW OF THE LITERATURE

2.1 DISTAL HUMERUS AND ELBOW

2.1.1 ANATOMY

The humerus is the largest bone in the upper limb. It articulates with the scapula at the glenohumeral joint and with the radius and ulna at the elbow joint (Moore 1999).

The elbow joint is formed by the distal humerus and the proximal radius and ulna. The distal end of the humerus widens as the sharp medial and lateral supracondylar ridges form, and then ends in medial and lateral extensions, the epicondyles, providing muscle attachment (medial epicondyyle for flexors and lateral for extensors). The distal end of the humerus includes the lateral and medial condyle with articular surfaces: a lateral capitellum for articulation with the head of the radius and a medial trochlea for articulation with the proximal end of the ulna. Superior to the trochlea anteriorly is the coronoid fossa (receives the coronoid process of the ulna during elbow flexion) and posteriorly the olecranon fossa (accommodates the olecranon during elbow extension). Superior to the capitellum anteriorly, a shallow radial fossa accommodates the edge of the head of the radius during elbow flexion (Moore 1999).

Figure 1. A) Anterior and B) posterior view of the distal right humerus. The radial fossa and capitulum are parts of the lateral condyle and trochlea and the coronoid fossa of the medial condyle.

Between the olecranon fossa posteriorly and the coronoid fossa anteriorly, the medial and lateral columns of the distal humerus are connected by a thin segment of bone, which makes this area especially vulnerable to fracture (Omid 2008, Skaggs and Flynn 2015).
The spiral orientation of the trochlea allows flexion and extension about an oblique axis; this brings the forearm from a position parallel to the humerus in full flexion to a valgus carrying angle (CA) of approximately 15° in extension with an increase in values until puberty (Tukenmez 2004, Rang 2005, Balasubramanian 2006, Golden 2007). The carrying angle has an evolutionary significance, allowing the upper extremity to carry an item with clearance of the pelvis as the arm swings (Rang 2005). CA is greater in girls (Balasubramanian 2006, Golden 2007). The elbow joint also allows pronation and supination about the long axis of the forearm (Rang 2005).

Range of motion (ROM) of the elbow is defined as the sum of total flexion plus total extension, or the complete arc of motion of the elbow joint. Total ROM (especially flexion) correlates positively with age. This is thought to be explained by the impingement of the arm and forearm at the endpoint of flexion, as very young children are reported to have more adipose tissue in the antecubital fossa compared to older children (Golden 2007). Girls are reported to have greater total ROM (especially extension), which may be related to increased ligamentous laxity (Golden 2007).

2.1.2 DEVELOPMENT

The elbow joint has six secondary ossification centers of which four are located in the distal humerus. The sequence of ossification by Cheng et al. (1998) is: capitellum one year, radial head 5–6 years, medial epicondyle 5–7.5 years, olecranon 8.7–10.5 years, trochlea 9–10.7 years and lateral epicondyle 10–12 years. In general, the time of physeal closure in girls precedes that of boys and the difference between the sexes may be as great as two years. The highly variable pattern of development of the distal humerus may present difficulties in fracture diagnosis from radiographs if clinicians are not familiar with the normal development of the distal humerus.
Figure 2. Secondary ossification centers of the distal humerus.

The rate of fracture remodeling is affected by the age and sex of the child (remaining growth potential) and the location of the fracture. Long bones do not grow equally on both their physis. Only 20% of humeral growth is from its distal part, providing little remodeling potential (Digby 1915, Rathjen and Kim 2015). The humerus is about 30 cm long at skeletal maturity. Approximately 65% of the length of the humerus is achieved by age of six years. A six-year-old child has approximately 10 cm of growth left in the entire humerus, with only approximately 2 cm provided by the distal physis (Skaggs and Flynn 2010). Some remodeling potential in the sagittal plane has been reported (Moraleda 2013, Guven 2015). Skaggs and Flynn (2015) have suggested that in toddlers (under three years old) nonoperative treatment of a Gartland type II fracture in which the capitellum abuts the AHL but does not cross it could be accepted. Whereas in children aged over eight years, there is only 10% of growth of the distal humerus remaining and adequate reduction and stabilization is essential to prevent malunion.
2.2 SUPRACONDYLAR HUMERUS FRACTURE

2.2.1 EPIDEMIOLOGY AND CLASSIFICATION

SCHFs are the most common distal humerus fractures in children (Otsuka 1997, Cheng 1999, Houshian 2001). Most SCHFs occur at the age of 5–7 years (Cheng 2001). Children with flexion-type fractures (see below) are reported to be older than extension-type fracture patients (5.8 vs 7.5 years) (Mahan 2007). In an epidemiological study of elbow fractures in children under 15 years of age in a single hospital in Denmark between 1993 and 1997, the incidence of SCHF was 180/100 000 per year (Houshian 2001). In a registry study of 0–18-year-old hospital-treated patients in Finland, Salonen et al. (2013) found an increase in the incidence of distal humeral fractures (30%) and of reduction with osteosynthesis in prepubertal children (2–5-fold) over a 24-year study period (from 1987 to 2010). An increase in pin fixation rate (from 4% to 40%) was also reported in an earlier 10-year study (6493 fractures, from 1985 to 1995) in Hong Kong (Cheng 1999). Although the fracture incidence is generally reported to be higher in boys, recent studies indicate that the frequency in girls and boys seems to be equalizing (Farnsworth 1998, Cheng 1999, Houshian 2001). The fractures most commonly occur on the left side (Farnsworth 1998, Cheng 1999).
Playground equipment accidents represent a major mechanism of SCHF injury in children (such as on a trampoline, monkey bars, slides), following accidents involving home furniture. Two out of five fractures are reported to occur after a fall unrelated to equipment (Siriwardhane 2012). SCHFs can be divided into extension (97–99%) and flexion (1–3%) types depending on the trauma mechanism and the direction of the displacement of the distal fragment (Cheng 2001, Mahan 2007). Extension-type SCHFs are usually caused by a fall onto an outstretched hand with the elbow in full extension. When the elbow is hyperextended, the olecranon engages the olecranon fossa and acts as a fulcrum through which the extension force can cause a fracture across the medial and lateral columns. With the anterior capsule simultaneously providing a tensile force on the distal humerus proximal to its insertion, an extension-type SCHF is created (Abraham 1982). In flexion-type fractures, the trauma mechanism is believed to be a fall directly onto the elbow rather than onto an outstretched upper limb.

Generally, in extension-type fractures, posteromedial displacement of the distal fragment is more common than posterolateral displacement (approximately 75% of patients) (Louahem 2006). Displacement of the distal fragment determines which soft tissue structures are at risk. Medial displacement puts the radial nerve at risk and lateral displacement puts the median and brachial artery at risk (Kwok 2016). The direction of fracture displacement often indicates whether the medial or lateral periosteum is intact. A posteromedially displaced fracture has an intact medial periosteum: pronation places the median periosteum under tension, thus closing the hinge and correcting varus malalignment (supination in posterolaterally displaced fractures) (Rang 2005, Omid 2008). A way of indicating this is to turn the patient’s thumb towards dislocation of the distal fracture fragment when reducing the fracture.

The Gartland classification is the most commonly used classification of extension-type SCHF (Gartland 1959). The original classification included three grades: I, undisplaced; II, posteriorly hinged with intact posterior cortex; and III, completely displaced without cortical contact. A modified Gartland classification with a fourth grade (IV) has also been presented and which requires testing of fracture stability with manipulation under imaging (unstable fracture both in flexion and extension) (Leitch 2006). Regardless of the fracture grade, one should pay attention to possible collapse of the medial column which leads to varus deformity and which should be reduced (Leitch 2006). In epidemiological studies, the incidence of different Gartland fracture grades has differed significantly (Houshian 2001 from Denmark vs Cheng 2001 from Hong Kong: grade I, 64%/30%; grade II, 19%/24%; grade III, 18%/45%).
In flexion-type SCHF, fracture classification is similar to extension type: type I, nondisplaced; type II, minimally angulated with cortical contact; and type III, totally displaced fracture. A key to recognizing a flexion-type SCHF is its instability in flexion, which may not be recognized until reduction is attempted (Mahan 2007).

2.2.2 SIGNS AND SYMPTOMS

An elbow or forearm fracture should be suspected in a child with elbow pain or swelling, or in a child who fails to use the upper extremity after a fall or trauma. In a prospective multicenter study, only 4% of children with full elbow extension had a fracture, whereas in children with restricted elbow extension, a fracture was diagnosed in 43% of cases after trauma. Half of these patients were diagnosed with SCHF (Appelboam 2008). Point tenderness over the medial and lateral columns suggests SCHF, as opposed to tenderness on only one side of the elbow, which suggests another type of distal humerus injury.

In type III fractures, the arm assumes an S-shaped appearance (Brubacher 2008). In displaced fractures, an anterior pucker sign may be present if the proximal fragment has penetrated the brachialis muscle and the anterior fascia of the elbow. A pucker sign indicates an increased risk of compromised blood circulation (11/12 children had a diminished or absent pulse) and median nerve injury (2/12 children in a study by Smuin et al. 2017). Open pattern in pediatric SCHF is rare (0.5%) (Cheng 2001).

Meticulous vascular, motor and sensory examinations should be performed in all patients and recorded routinely. The vascular examination includes determining the color and warmth of the hand as well as capillary refill and the presence of a radial pulse. Assessment of the vascular status is essential, as studies report compromised distal blood circulation in up to 15% of children with displaced SCHF (Dormans...
The vascular status may be classified into one of three categories: I, red and warm and radial pulse present; II, well perfused hand but absent radial pulse; and III, blue or blanched and cool hand with absent radial pulse (Omid 2008).

Motor examination can be performed quickly by “thumbs up” (extension of wrist and thumb/radial nerve, flexion of digits II–III/median nerve) and “OK” (abduction of digits III–V/ulnar nerve, flexion of index and thumb DIP and IP/AIN) tests. Sensation should be tested in discrete sensory areas of the radial nerve (first web space dorsal), medial nerve (palmar index finger), and ulnar nerve (palmar little finger) (Rang 2005, Skaggs and Flynn 2015).

### 2.2.3 Diagnosis

Plain radiographs for diagnostic purposes should be taken if a distal humerus fracture is suspected (generally including sagittal and coronal views of the elbow). Diagnosis and classification of SCHF is made on the basis of plain radiographs. However, one should notice that initial radiographs may show no evidence of a fracture except for a positive fat-pad sign. In a series of 34 patients with traumatic elbow pain and posterior fat-pad sign (without visible fracture line), 18 (53%) had a SCHF, nine (26%) had a proximal ulna fracture, four (12%) had a fracture of the lateral condyle and three (9%) had a fracture of the radial head at follow-up radiography (Skaggs 1999).

Computed tomography (CT) is rarely needed for SCHF diagnosis or classification. T-condylar distal humerus fractures are most often confused with extension-type supracondylar fractures. If T-condylar fracture diagnosis is suspected after a meticulous evaluation of the plain radiographs, it can be confirmed with a CT scan for adolescent children (MRI in younger children) (Shore 2015). It is suggested that CT is helpful if there is a doubt concerning rotational malalignment of SCHF (Hindman 1988, Adlercreutz 2009). The difference between the angles of the flat dorsum of the distal part of the humerus and the fracture fragment is the degree of rotational dislocation. Rotation greater than 10° resulted in an abnormal Baumann angle and a cubitus varus deformity in a study by Hindman (1988).

Even though MRI is more sensitive in diagnosing distal humerus fracture than plain radiographs, the effect of MRI on patient treatment is negligible. In a study of 50 children with elbow trauma examined using both radiographs and MRI, radiographs showed a total of 27 fractures, whereas MRI showed 38 fractures (fracture types not identified). Additional findings shown by MRI did not lead to treatment modification in any child (Griffith 2001). In a young child, an epiphyseal separation (the fracture propagates through the physis without a metaphyseal fragment) can mimic SCHF.
with gross swelling about the elbow and marked discomfort. MRI or ultrasonography can be used for diagnostic purposes.

**Radiographic parameters**

![Image of Baumann angle](image.png)

**Figure 5.** Illustration of Baumann angle.

The **Baumann angle**, the angle between the long axis of the humeral shaft and the physeal line of the lateral condyle in the coronal plane, was first described by Ernest Baumann in 1929 (Baumann 1929). A normal range of 64° to 81° is reported (Williamson 1992). An increase in the BA indicates varus angulation and correlation of increased BA with clinical varus deformity has been described (Dai 1999). No variation of BA by age, sex or laterality has been reported (Shank 2011).

Shank et al. (2011) found excellent intra-observer reliability (r=0.86) of BA assessment, relatively consistent across different age groups. Inter-observer reliability was also considered excellent (mean r=0.80). Silva et al. (2010) have also reported good (r=0.78) inter-observer and excellent (r=0.80) intra-observer reliability.
The **anterior humeral line** (AHL) crosses the capitellum through the middle or anterior third on a true sagittal radiograph of the elbow in the majority of children. Especially in children younger than four years of age, the line passes with nearly equal frequency through the anterior and middle thirds of the capitellum (Herman 2009).

Alignment, in which the AHL does not cross the capitellum in Gartland grade II fractures, is commonly considered unacceptable. However, this could be because of translational deformity, which is likely to remodel, rather than because of angular deformity, which may not remodel reliably (Shank 2011). Thus, according to Shank et al. (2011), the angulation between the humeral shaft and the capitellar physis may be a more accurate measure of distal humerus sagittal plane alignment.

The intra- and inter-observer reliability of assessing the AHL crossing point with the capitellum was found to be moderate to substantial ($r=0.54–0.80$) in a study by Herman et al. (2009).
Shank et al. (2011) defined the **lateral capitellohumeral angle (LCHA)** as the angle between capitellar physis and the anterior humeral cortex with normal values of $51^\circ \pm 6^\circ$. Simanovsky et al. (2008) measured a complement of the LCHA (which they named the humerocondylar angle) with a mean of $42^\circ \pm 6^\circ$. No significant difference has been found between age groups, sexes or the right and left elbow (Simanovsky 2008, Shank 2011).

Reported intra-observer reliability is moderate in 0–2-year-old children ($r=0.51$) but improves with older children and is excellent in children over eight years of age ($r=>0.80$). However, inter-observer reliability is only fair (mean $r=0.37$) (Shank 2011). Simanovsky et al. (2008) do not recommend the use of LHCA alone for final decisions in the evaluation and treatment of SCHF due to significant individual variation (range 30–70°).
2.2.4 TREATMENT

**Gartland grade I**

Gartland grade I SCHF can be treated without internal fixation. Immobilization with a collar and cuff or an above-elbow back slab for three weeks in ≥90° of flexion is suitable (Omid 2008, Skaggs and Flynn 2015). Oakley et al. (2009) studied back slab versus collar and cuff immobilization in 50 cases of nondisplaced SCHF and found no statistically significant difference in the duration or intensity of pain.

**Gartland grade II**

Treatment of Gartland grade II fractures remains controversial. Reduction is advocated in cases where the AHL does not cross the middle or anterior third of the capitellum. The fracture can be reduced using closed means and then holding the reduction by flexing the elbow greater than 120°. Even so, fear of increased compartment pressure has caused authors to avoid the use of hyperflexion to maintain reduction of SCHFs. In their Doppler examination study, Mapes and Hennrikus found decreased flow in the brachial artery in increased elbow flexion after operative treatment of Gartland grade II and III fractures. In grade II fractures, with the forearm in supination, the radial pulse disappeared at a mean elbow flexion angle of 128°, and in grade III fractures, it disappeared at a mean elbow flexion angle of 104°. This led to the recommendation to stabilize fracture reduction with pin fixation and to immobilize the elbow in less flexion if the fracture would otherwise need elbow flexion of >90° to hold the reduction.

In reduced fractures not stabilized with pins, there is a risk of loss of reduction. In a series of 61 Gartland grade II fractures treated with closed reduction and casting, nonoperative treatment failed in 20% of cases (Fitzgibbons 2011). Greater extension deformity at the time of presentation was reported as a risk factor for LOR. Likewise, a study by Spencer et al. (2012) showed that a nonoperative approach was likely to fail for Gartland grade II fractures with initial rotational deformity, coronal malalignment and significant extension of the distal fragment. It is recommended that reduced fractures without stabilizing pins be followed-up with radiographs (Omid 2008).

**Gartland grade III**

Dunlop introduced a skin traction for treatment of Gartland grade III SCHF in the late 1920s (Dunlop 1939). This reduced the rate of vascular complication significantly
but still resulted in up to 33% cubitus varus deformity (Allen 1945, Prietto 1979). Overhead skeletal traction with a K-wire or a screw in the olecranon was later shown to give better control of the fracture reduction (Palmer 1978). Nowadays, traction as the definitive treatment for SCHF in children is largely due to a historic interest in most modern centers. Still, some authors argue that traction provides similar long-term functional and cosmetic outcome with the benefit of no iatrogenic nerve or vascular complications compared to operative treatment with K-wires (especially in children aged under 10 years old in a study of straight-arm traction by Gadgil et al. 2005). The rate of conversion of overhead skeletal traction to reduction and K-wire fixation was 3/44 in a study by Young et al. (2010). No statistically significant difference between traction and pin fixation was reported in deformity rate or in nerve or vascular injuries. The rate of secondary pin fixation was even greater (10%) in a study of 151 cases of SCHF initially treated with olecranon screw traction (Lewis 2007). Indications for traction may include severe comminution, no anesthesia available, a medical condition prohibiting anesthesia, lack of an experienced surgeon to perform reduction and pinning of the fracture, or temporary traction to allow swelling to decrease (Skaggs and Flynn 2015).

In 1948, Swenson introduced percutaneous crossed pin fixation for treatment of SCHF in children (Swenson 1948). Flynn et al. published a long-term follow-up study of 52 cases of percutaneously pin-fixed SCHF with satisfactory results (Flynn’s classification of outcome) in 98% and no Volkmann’s contractures (Flynn 1974). Percutaneous K-wire fixation was named as the method of choice for the majority of displaced fractures by Pirone et al. (1988) in their long-term study (mean five-year follow-up) of 230 children with SCHF, comparing percutaneous pin fixation (excellent result in 78% of cases), skeletal traction (excellent result in 67% of cases) and open reduction with internal fixation (excellent result in 67% of cases). Nowadays, in general, displaced Gartland type III fractures are best treated by manipulation under anesthesia and pin fixation (Omid 2008, Mulpuri 2012, Skaggs and Flynn 2015). A closed reduction should be initially attempted in all fractures, unless the fracture is open (Omid 2008, Skaggs and Flynn 2015).

Open reduction is indicated in failed closed reduction cases, a loss of pulse or a poorly perfused hand following reduction, and in open fractures (Skaggs and Flynn 2015). A considerable gap in the fracture site or an irreducible fracture with a rubbery feeling on attempted reduction may be signs of the median nerve and/or brachial artery being trapped at the fracture site (Skaggs and Flynn 2015). Surgical exposure can be accomplished with a variety of approaches: anterior, posterior, lateral or medial (Pretell-Mazzini 2010 A, Wingfield 2015). The open reduction rate in a study of 200 cases of pin-fixed SCHF was 5% (Gosens 2003). No compartment syndrome, vascular injury nor nonunion was reported in a review study of 226 patients operated on by open means. The reported overall nerve injury rate was 2% and the pin tract infection rate 8% (Pretell-Mazzini 2010 A). Long-term functional
outcome is reported to be more likely or equally satisfactory in the closed approach compared to the open approach (Kumar 2002, Ozkoc 2004). Cosmetic results were satisfactory in 95% of both open and closed approach techniques (Ozkoc 2004).

An advantage of the anterior approach is that it allows direct visualization of the brachial artery and median nerve as well as the fracture fragments. Furthermore, this approach does not disrupt the posterior periosteal hinge, which is useful for fracture reduction (Skaggs and Flynn 2015). In extension-type SCHF, the posterior approach is not recommended. Avascular necrosis of the trochlea was diagnosed in 2/23 children operated on via the posterior approach (Aktekin 2008). The posterior approach has also the highest risk of ulnar nerve injury and is associated with poor functional outcome according to the Flynn’s criteria in every third patient (Pretell-Mazzini 2010 A).

Restoration of the BA on the coronal view, communion of the medial and lateral columns on oblique views, and the AHL passing through the middle or anterior third of the capitellum on the sagittal view indicate a successful reduction (Herman 2009, Skaggs and Flynn 2015). The reduction is held with two or more K-wires. There are two pin configuration considerations: crossed pins versus lateral-entry pins. The preferable fixation method has been debated in the literature in relation to the risk of iatrogenic nerve injury and the stability of fixation.

Median pin significantly increases the risk for ulnar nerve injury (up to 4%) and lateral pinning increases the risk for median nerve injury (up to 2%) (Babal 2010, Bashyal 2009, Woratanarat 2012). A mini-open approach over the medial epicondyle to ensure that the ulnar nerve is not injured by the pin has been suggested (Gosens 2003, Khademolhosseini 2013). The risk of iatrogenic ulnar nerve injury is reported to be greater, if the elbow is at hyperflexion at pin insertion (Omid 2008).

In a recent systematic review of stiffness for various pin configurations, no statistically significant differences between crossing pins and two divergent lateral pins were found. An additional pin did not strengthen the two-pin construct but stabilized fractures with medial comminution better (Chen 2015). In meta-analyses of 1158 patients by Dekker et al. (2016) and of 1615 patients by Woratanarat et al. (2012), no difference in the outcome was found between different pin configurations according to Flynn’s criteria or in LOR.

An ideal pin separation at the fracture line has not been determined in the literature, even though a minimum of 3 mm separation for lateral pins (Omid 2008, Skaggs and Flynn 2015, Reisoglu 2017) and 13 mm or one-third of the width of the humerus at the fracture level for crossed pins has been suggested (Pennock 2014). In a study by Reisoglu et al. (2017), pin spread at the fracture line did not differ in patients with LOR (12 mm, 39% of humerus width at fracture level) compared to patients without LOR (14 mm, 41% of humerus width at fracture level).

Postoperative radiographs after one week and at pin removal are commonly performed after operative treatment of SCHF. Even though pin migrations and mild
changes at alignment have been reported, the effect of postoperative radiographic controls on clinical management has been questioned in several studies (Ponce 2004, Karamitopoulos 2010, Schlechter 2015, Karalius 2017).

The optimum time window for surgical treatment of displaced SCHF has been a matter of much debate. Emergent pin fixation has been justified to stop swelling, which could at least theoretically reduce the number of open reductions and decrease complications such as compartment syndrome, nerve injuries and infections (Mehlman 2001). However, significant differences in complication rates have not been found between patients with closed SCHF without compromised distal blood circulation treated emergently and semi-electively (Silva 2011, Mayne 2014, Schmid 2015). It has thus been proposed that pin fixation of a displaced SCHF in a child without signs of vascular injury can be safely performed within 24 hours of the injury (Mehlman 2001, Leet 2002, Gupta 2004, Sibinski 2006, Scannell 2013). Even though a systematic review of 400 Gartland grade III fractures showed a higher risk of failure for closed reduction and conversion to open reduction in a delayed-treatment group (35/153, 23%) compared to an early-treatment group (27/243, 11%), other studies show no increase in risk for open reduction (Loizou 2009, Mayne 2014, Silva 2011, Schmid 2015).

**Flexion-type SCHF**

The treatment protocol for flexion-type SCHF is similar to that for extension-type fractures. A problem with type III flexion SCHF is that reduction is not easy to achieve, and when achieved, the elbow is usually in extension, making pinning of the fracture challenging. The rate for the open approach is greater than in extension-type fractures (31% vs 10%) (Mahan 2007).

### 2.2.5 COMPLICATIONS

**Vascular injury**

Approximately 10–15% of children with Gartland grade III SCHF present with an absent radial pulse (Shaw 1990, Dormans 1995, Sabharwal 1997, Louahem 2006). Fracture reduction usually restores the pulse, thus angiographic studies potentially delaying fracture reduction are not recommended (Shaw 1990, Choi 2010, Louahem 2016). The incidence of impaired distal blood circulation after reduction of displaced SCHF was 3% in a study of 200 operatively treated patients (Gosens 2003). The perfusion of the hand and the radial pulse should be evaluated after closed reduction and pin fixation. White et al. (2010) found in their systematic review of 331 cases of
pulseless SCHF that 70% of children with a SCHF and a pink pulseless hand, and who had no return of palpable radial pulse after closed reduction, had a documented brachial artery injury (spasm in only 9%). However, after an average of 20 months follow-up, children with a perfused, pulseless SCHF treated with closed reduction, percutaneous pinning and observation demonstrated a palpable distal radial pulse, normal growth of the arm and good/excellent functional outcomes, although 5/20 of the patients had an occluded brachial artery (Scannell 2013). Thus, most children without a palpable radial pulse maintain adequate distal perfusion, and the absence of a palpable pulse alone is not an indication for exploring the brachial artery. However, loss of intact preoperative radial pulse after closed reduction and pinning is a strong indicator for brachial artery exploration when accompanied by evidence of impaired circulation of the hand. Either direct arterial entrapment at the fracture or arterial compression by a fascial band pulling across the artery may cause compromised perfusion after fracture reduction (Omid 2008, Skaggs and Flynn 2015). Early repair of the brachial artery (vein-patch angioplasty or end-to-end anastomosis) was associated with asymptomatic re-occlusion and residual stenosis in three quarters of patients in a study by Sabharwal et al. (1997).

**Compartment syndrome**

Compartment syndrome is estimated to occur in less than 0.5% of patients with Gartland grade III SCHF (Battaglia 2002, Bashyal 2009). In acute compartment syndrome, increased pressure in a closed fascial space causes muscle ischemia. With untreated ischemia, muscle edema increases, further increasing pressure, decreasing flow, and leading to muscle necrosis and fibrosis. Compartment syndrome in the forearm may occur with or without brachial artery injury and in the presence or absence of a radial pulse. In a multicenter study, Ramachandran et al. (2008) found that significant swelling at presentation and delay in fracture reduction may increase the risk of development of compartment syndrome even in children with a closed, low-energy supracondylar fracture without vascular compromise at presentation. The diagnosis of compartment syndrome is based on resistance to passive finger movement and dramatically increasing pain despite satisfactory reduction and pin fixation of the fracture. Emergent surgical decompression (fasciotomy) is recommended (Skaggs and Flynn 2015). Special attention must be paid to SCHF with median nerve injury, as the patient will not feel pain in the volar forearm compartment (Hosseinzadeh 2016).

If the treatment of acute forearm compartment syndrome is delayed or there is inadequate decompression, muscle ischemia and necrosis results, leading to fibrosis. The typical wrist and finger flexed deformity, Volkmann ischemic contracture,
develops, resulting in the loss of active finger motion and leaving the hand with little functional value (Pettitt 2012).

Nerve injuries

The incidence of nerve injury associated with SCHF is 11% according to a meta-analysis of 5,154 cases of SCHF by Babal et al. (2010). The anterior interosseous nerve (AIN) appears to be the most commonly injured nerve with extension-type fractures (5%), followed by the radial nerve (4.5%), median nerve (3%), ulnar nerve (2%) and posterior interosseous nerve (PIN) (1%). In a flexion-type supracondylar fracture, the ulnar nerve is most likely to be injured and the overall risk of nerve injury is greater than in extension-type fractures (17% vs 11%) (Babal 2010). Regardless of which nerve is injured, neural recovery generally occurs in the first 2–3 months, but may take up to 6–8 months (Gosens 2003, Khademolhosseini 2013). Exploration of the injured nerve is not indicated in a closed fracture.

The reported risk of iatrogenic nerve injury is up to 4% (Babal 2010, Woratanarat 2012). A median pin significantly increases the risk of ulnar nerve injury (up to 4%) and lateral pinning increases the risk of median neuropathy (up to 2%) (Bashyal 2009, Babal 2010, Woratanarat 2012). No significant difference in the risk of radial nerve injuries between the lateral and medial pinning technique has been reported (Babal 2010). The mini-open technique is advised by some authors to reduce the risk of penetrating a nerve during pinning (Gosens 2003, Khademolhosseini 2013). Slobogean et al. (2010) calculated that there is one iatrogenic ulnar nerve injury for every 28 patients treated with crossed pinning compared to lateral pinning based on a meta-analysis of 2,639 patients.

Routine surgical exploration of the ulnar nerve after postoperative ulnar nerve dysfunction is not recommended (Khademolhosseini 2013). The medial pin rarely directly impales the ulnar nerve but more commonly constricts the nerve in the cubital tunnel (Belhan 2009, Khademolhosseini 2013). Recovery of the ulnar nerve is reported without prior removal of the causative pin (Lyons 1998, Khademolhosseini 2013).

Pin track infections

The reported prevalence of pin track infections in SCHF is close to 1% (Cheng 1995, Gupta 2004, Bashyal 2009). In a series of 622 operatively treated SCHFs, one patient (0.2%) developed a deep infection (Bashyal 2009). Skin preparation and prophylactic antibiotic use have not been shown to reduce pin track infections (Bashyal 2009). SCHF was reported as the most common reason for postoperative
pin track infection (5/12 infections) in a study of 1,583 K-wires in 884 children (Tosti 2015). Pin track infections generally resolve with pin removal and oral antibiotics. Fortunately, by the time a pin track infection develops, the fracture is usually stable enough to remove the pin without LOR (Skaggs and Flynn 2015).

**Pin migration**

In a review of 622 operatively treated SCHF, Bashyal et al. (2009) reported pin migration beneath the skin as the most common complication necessitating unexpected return to the operating room for pin removal, in 11 (1.8%) patients.

**Loss of reduction**

The reported risk of LOR in pin-fixed SCHF is between 1% and 4% (Bashyal 2009, Pennock 2014). In recent studies, no statistically significant difference in LOR between lateral and cross pins has been found (Kocher 2007, Tripurarneni 2009, Gaston 2010, Woratanarat 2012, Pennock 2014, Chen 2015).

In mechanical testing of different lateral pin configurations, divergent pins provided statistically greater stability than parallel pins under varus and valgus loading (Lee 2002). A lateral pin configuration was found to have the highest torsional resistance and a trend toward greater resistance in valgus testing, with the greatest divergence at the fracture line (Hamdi 2010). A greater pin diameter (2.0 mm compared to 1.6 mm) provides improved stiffness with regard to rotational stresses (Gottschalk 2012 B).

**Loss of elbow ROM**

Loss of motion after extension-type supracondylar fractures is rare in children. Although motion loss is usually minimal, significant loss of flexion can occur. This problem is generally caused by a poor fracture reduction (Skaggs and Flynn 2015). In a report of 63 children with a SCHF stabilized with either two or three lateral-entry pins, elbow ROM returned to 72% of contralateral elbow motion by six weeks postoperatively and progressively increased to 86% by 12 weeks, 94% by 26 weeks, and 98% by 52 weeks (Zionts 2009).
Nonunion

No reported nonunion of pediatric SCHF was found in the literature. The author of this study is familiar with one patient case via personal communication (Nietosvaara).

Myositis ossificans

Myositis ossificans (traumatica) is a condition in which calcifications occur at the site of injured muscle. Four cases of myositis ossificans related to SCHF have been reported, of which two were treated nonoperatively and two operatively (Hartigan 2001, Naranje 2012, Sferopoulos 2017). No specific reason for developing myositis ossificans was given.

Avascular necrosis

The blood supply to the trochlea is fragile: its medial part is vascularized by a small lateral artery which courses through the physis of the medial condyle. This artery can be injured in very distal fractures, leading to AVN of the ossification center of the trochlea, causing fishtail deformity. In open reduction through a posterior approach, the risk of AVN increases (Pretell-Mazzini 2010 A). Two instances of avascular necrosis of the trochlea were diagnosed in a patient group of 23 children with open reduction via a posterior approach (Aktekin 2008). Pain, reduced ROM of the elbow, posttraumatic arthrosis, loose bodies and occasional locking of the elbow, as well as proximal migration of the ulna and radial subluxation associated with fishtail deformity, have been reported (Storm 2006, Glotzbecker 2013, Narayanan 2015).

Cubitus varus

Cubitus varus, also known as gun-stock deformity, is the most well-known complication after SCHF. Even though it has been proposed that unequal growth in the distal humerus causes cubitus varus deformity, this is unlikely, as distal humerus growth is only 20% of the whole growth potential of humerus (Digby 1915). Therefore, malunion is proposed to be the most common reason for cubitus varus rather than growth arrest (Weiland 1978).

Treatment for cubitus varus has been considered mostly for cosmetic reasons. However, there are functional consequences of this deformity, such as increased risk of lateral condyle fractures, pain and snapping of the ulnar nerve over the medial epicondyle, and inability to carry a burden (Davids 1994, Spinner 1999).
Good to excellent outcomes and adequate correction of varus deformity in the coronal plane can be achieved with a number of osteotomy techniques. However, a risk of major complications (residual varus deformity, nerve injury, infection, LOR leading to reoperation and growth arrest) of up to 25% has been reported (Raney 2012, Solfelt 2014).

### 2.2.6 LONG-TERM OUTCOME

**Deformity and ROM**

The objective long-term outcome of SCHF is usually assessed clinically with Flynn’s criteria, which define unsatisfactory results as more than 15° asymmetry in elbow CA and ROM.

<table>
<thead>
<tr>
<th>Results</th>
<th>Loss of motion (°)</th>
<th>Loss of carrying angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satisfactory Excellent</td>
<td>0–5</td>
<td>0–5</td>
</tr>
<tr>
<td>Good</td>
<td>6–10</td>
<td>6–10</td>
</tr>
<tr>
<td>Fair</td>
<td>11–15</td>
<td>11–15</td>
</tr>
<tr>
<td>Unsatisfactory Poor</td>
<td>&gt;15</td>
<td>&gt;15</td>
</tr>
</tbody>
</table>

Table 1. Assessment of treatment outcome by Flynn’s criteria

In their study of 46 children in Spain with Gartland grade II SCHF treated in situ with splint immobilization, after a mean follow-up time of seven years, a mild decrease in CA (injured 9° of valgus vs uninjured 12°) and increase in elbow extension (injured 13° of hyperextension vs uninjured 7°) were reported. Long-term outcome was good or excellent according to Flynn’s criteria in 37/46 children (Moraleda 2013).

Guven et al. (2015) evaluated the long-term functional and cosmetic result of 49 cases of Gartland grade III SCHF treated with open reduction and cross-pin fixation in their retrospective study in Turkey (follow-up rate 12%, mean follow-up time 22 years). According to the Flynn criteria, the cosmetic outcome (CA) was good or excellent in 43/49 and the functional outcome (ROM) was good or excellent in 33/49 of the children. No correlation between the BA measurements and clinical CA values was found. The last follow-up radiographs (range 10–38 years) showed no signs of degenerative arthritis.

In a study by Sinikumpu et al. (2016) in Finland (follow-up rate 76%), good or excellent results according to the Flynn score were achieved in 22/33 children with Gartland grade II and III SCHF pin fixed either percutaneously or openly after a minimum follow-up time of 10 years.
In a retrospective study in Korea of 154 SCHFs (mean follow-up 3 years) treated with closed reduction and pin fixation, a fracture below the humeral isthmus (14% of fractures) was associated with poor prognosis in terms of ROM, angulation and Flynn grade. Age over 10 years was also a poor prognostic factor for recovery of ROM (Wang 2017).

Simanovsky et al. (2007) retrospectively reviewed 223 SCHFs operated on in their institution in Israel and found under-reduction of the extension component in 30 of the children. The proportion of these children followed-up (mean 8.2 years) was 22/30. Radiographic remodeling, ROM and awareness of the patients of the functional limitation were evaluated. Ten children had an unsatisfactory result according to Flynn’s criteria for ROM, but only three of them felt minor subjective functional disability. Ten children had >5° asymmetry in elbow flexion and three children considered it to be a functional problem. In seven children, mild (up to 7°) elbow hyperextension was present, and none of them considered it to be a functional problem. Radiographic remodeling was reported in only five children (correction of anterior inclination was diagnosed at the last follow-up of a minimum of 6 years).

**Nerve injury**

In a long-term functional outcome study of 29 SCHFs with neurological injury (14 radial, 13 median and nine ulnar) in Spain, 16 children (eight ulnar, seven median and six radial) returned for clinical evaluation of grip and pinch tests and examination of sensibility after an average follow-up time of 9 years. The children also completed the quickDASH questionnaire. The functional results were excellent in the majority of children. However, almost half of the children exhibited paresthesias, mostly in the ulnar nerve territory. Unfortunately, the origin of the nerve injury (fracture- or treatment-related) was not determined in their retrospective study (Valencia 2015).

In their long-term (mean duration of 38 months) functional outcome study of 23 nerve injury patients (eight median, nine radial, four AIN and three ulnar, nine with simultaneous vascular injury, iatrogenic injuries excluded), Wang et al. (2017) reported no difference in outcome compared to patients without neurovascular injuries (n=121) measured by the QuickDASH and PODCI questionnaires.

**Pain**

In their study of 46 children with Gartland grade II SCHF, Moraleda et al. (2013) reported seven children with pain in the elbow at the time of follow-up (three at physical activity, two at lateral elbow instability testing and two who complained
of discomfort). In the study by Sinikumpu et al. (2016), 9/25 of patients who had had Gartland grade III fractures experienced pain.

**Subjective outcome**

The subjective outcome has been evaluated with validated scoring systems such as the Pediatric Outcome Data Collection Instrument (PODCI), the Mayo Elbow Performance Score and QuickDASH. The validity of the QuickDASH questionnaire for children and adolescents (8–18-years of age) with upper extremity pathology has also been established (Quatman-Yates 2013).

In the study by Sinikumpu et al. (2016), the subjective outcome of 81 children was assessed using the Mayo Elbow Performance Score (most of the children had nondisplaced SCHF that was treated nonoperatively). The Mayo score in the 25 children with Gartland grade III fractures was excellent (mean 93, range not reported).
2.3 LATERAL HUMERAL CONDYLE FRACTURE

2.3.1 EPIDEMIOLOGY AND CLASSIFICATION

Lateral condyle fractures are the second most common distal humerus fracture type in children (12–17%). The majority of patients are in preschool (4–10 years old) (Landin 1986, Sawyer and Beaty 2015). The trauma mechanism (“pull-off”) is falling with the forearm in supination and with the elbow twisting to varus, resulting in avulsion injury of the forearm extensors (Jacob 1975, Rang 2005, Gonola 2006, Tejwani 2011). A “push-off” mechanism has also been suggested, in which the radial head pushes the lateral condyle off. It is likely that both mechanisms can produce this fracture. The more common fracture type, which extends to the apex of the trochlea, is a result of avulsion forces, and rare physeal fracture coursing through the ossific nucleus of the capitellum is a result of the radial head being forced against the capitellum (Sawyer and Beaty 2015).

Lateral condyle fractures can be classified by either the fracture line’s anatomical location or the amount of displacement.

![Figure 8. Anatomical location of the lateral condyle classified by Milch (Milch 1964).](image)

A: Type I: fracture line passes lateral to the trochlear groove; elbow is stable.
B: Type II: fracture line extended into trochlear groove or medial to it; elbow instability is possible.

The amount of fracture displacement as classified by Weiss is: type I, fractures are displaced <2 mm; type II, >2 mm displacement with an intact cartilaginous hinge; and type III, >2 mm displacement without an intact cartilaginous hinge. In their series of 158 type II and III fractures, Weiss et al. (2009) found that type II fractures had less than 4 mm of dislocation on initial radiographs and type III more than 4 mm dislocation. This classification was found to be predictive of complications.
Because the usual fracture line disrupts the trochlea, the elbow joint may be unstable, creating the possibility of posterolateral subluxation of the proximal radius and ulna. Thus, the forearm rotates to valgus (Sawyer and Beaty 2015).

2.3.2 SIGNS AND SYMPTOMS

A lateral condyle fracture causes pain and swelling over the lateral aspect of the distal humerus (Sawyer and Beaty 2015).

2.3.3 DIAGNOSIS

Figure 9. A coronal plane radiograph of a lateral humeral condyle fracture in a six-year-old girl.

Diagnosis from plain radiographs (sagittal and coronal plane views) can be challenging, especially in patients less than five years old, as the fracture fragment is mainly cartilage. Oblique views may be helpful in patients in whom a nondisplaced or minimally displaced fracture is suspected, but not evident in AP and lateral views (Song 2008). Elbow arthrography is sensitive enough to diagnose intra-articular fractures, but its use is mainly limited to perioperative situations, when the quality of reduction needs to be assessed. Fracture morphology and stability can be evaluated with MRI, but children younger than school age do usually require sedation for imaging. In unclear situations, a CT scan is recommended (Gonola 2006, Tejwani 2011).
2.3.4 TREATMENT

Nonoperative treatment

Minimally displaced (<2 mm) fractures can be treated with cast immobilization alone (40% of lateral condylar fractures) (Jacob 1975). Immobilization time for lateral condyle fractures is longer than for other distal humerus fractures (intra-articular fracture) (Rang 2005, Gonola 2006, Tejwani 2011). Radiographic follow-up is recommended, since fracture alignment may worsen (Sawyer and Beaty 2015).

In a follow-up study of 95 minimally (≤2 mm) displaced lateral condyle fractures (acute trauma), closed treatment with a long-arm cast or splint immobilization resulted in a union in 93 patients within 3–7 weeks. Two of the fractures became displaced and subsequently went to union after open reduction and internal fixation (Bast 1998).

Operative treatment

In fractures with >2 mm displacement, closed or open reduction is required to restore anatomical alignment. Because of the risk of poor functional and cosmetic results with closed reduction methods, open reduction has traditionally been the advocated treatment method for unstable fractures with stage II or III displacement (60% of fractures) (Jacob 1975). However, normal ROM of elbow and no clinical or radiographic signs of complications were reported with closed reduction and percutaneous pinning of 12 lateral condyle fractures with >2 mm of dislocation. The authors thus recommend this technique for selected fractures with 2–4 mm of displacement with an arthrographically demonstrated congruent joint surface (open reduction if necessary) (Mintzer 1994). In their more recent study, Song et al. (2008) suggested that closed reduction and internal fixation is an effective treatment for unstable lateral condyle fractures, and open reduction would be necessary only if fracture displacement exceeds 2 mm after closed reduction. Fixation with pins in young children and screws in adolescents near skeletal maturity is mostly recommended (Sawyer and Beaty 2015).

2.3.5 COMPLICATIONS

Lateral condyle fractures are one of the rare pediatric fractures in which nonunion occurs (Rang 2005, Gonola 2006, Tejwani 2011). Nonunion can lead to valgus deformity, loss of motion, pain and delayed ulnar neuropathy. The treatment of nonunion depends on the time delay from the injury: in a study by Papandrea et
al. (2000) it is recommended that nondisplaced fractures less than three months old be treated with percutaneous pin fixation or cannulated screws, and older nonunion with open reduction and bone grafting. Varus deformity can also occur: the mechanism causing varus deformity is not fully understood; increased growth at the fracture line has been suggested (Tejwani 2011). A lateral condyle fracture can also result in a growth arrest and fishtail deformity (Gonola 2006).

2.4 MEDIAL HUMERAL EPICONDYLE FRACTURE

2.4.1 EPIDEMIOLOGY AND CLASSIFICATION

Figure 10. Illustration of a medial humeral epicondyle fracture.


There is no routinely used clinical classification of medial epicondyle fractures. A classification has been suggested which categorizes fractures into acute injuries
(undiplaced/minimally displaced, displaced, incarcerated with or without elbow dislocation) and chronic stress injuries (Stans and Lawrence 2015).

2.4.2 SIGNS AND SYMPTOMS

Clinical symptoms include: swelling, crepitation and loss of elbow motion. A medial epicondyle fracture associated with elbow dislocation appears with gross deformity of the elbow (Stans and Lawrence 2015). The distal neurovascular status finding (especially ulnar nerve function) should be carefully registered before conducting any procedures (Rang 2005, Gottschalk 2012 A, Stans and Lawrence 2015).

2.4.3 DIAGNOSIS

![Figure 11. A coronal plane radiograph of a medial epicondylar humeral fracture in a 13-year-old boy.](image)

Diagnosis is based on plain radiographs. If the medial epicondyle ossification center is visible in the sagittal plane radiograph, it is most likely positioned intra-articularly (Gonola 2006). If the fragment is totally incarcerated in the joint, however, it may be hidden by the overlying ulnar or distal humerus. The clue is the total absence of the epicondyle from its normal position just medial and posterior to the medial metaphysis (Stans and Lawrence 2015).

In a study of medial epicondyle fracture radiographs in 38 children, Pappas et al. (2010) reported poor intra- and inter-observer agreement with regard to fracture displacement measurement from plain radiographs and questioned the use of radiographic displacement as a criterion for choosing operative or nonoperative management. In a study by Edmonds et al. (2010), three-dimensional computed
tomography was found to be the most accurate method for assessing true fracture displacement. Fractures that were found to be minimally displaced or nondisplaced by radiographs may have had >1 cm of anterior displacement (3/11 children), for which operative treatment is usually recommended.

2.4.4 TREATMENT

Nonoperative treatment

The acceptable amount of fracture displacement in a medial epicondyle fracture is controversial. Reduction of intra-articular displaced medial epicondyle may be possible by closed means (forearm in supination, light flexion of elbow, valgus stress, passive extension of fingers) (Gonola 2006). It is suggested that the indications for nonoperative treatment include a low-energy mechanism, elbows stable to valgus stress, and minimal (<5 mm suggested) displacement of the fracture fragment (Rang 2005, Gonola 2006, Gottschalk 2012 A, Beck 2018).

Nonoperative treatment of a total of 19 (5–15 mm) displaced medial epicondyle fractures was reported to yield good long-term results similar to those obtained with open reduction (n=17) (subjective estimation of function, objective measurement of elbow ROM and forearm muscle atrophy, elbow stability and grip strength) and internal fixation in a retrospective long-term (mean 34 years) follow-up study in Italy by Farsetti et al. (2001), regardless of nonunion of the fracture fragment in most (17/19) of the nonoperatively treated patients.

Operative treatment

It is suggested that indications for operative treatment include high-energy injury, open fractures, incarcerated fracture fragment, elbow instability and intra-articular displaced fractures where there has been a failed closed reduction attempt (Rang 2005, Gonola 2006, Beck 2018). Ulnar nerve injuries associated with medial epicondyle fractures usually resolve spontaneously and exploration is not recommended (Gonola 2006, Stans and Lawrence 2015). Fixation can be performed by K-wires or cannulated screws (especially in patients at the end of the growth period) (Rang 2005, Gonola 2006, Gottschalk 2012 A, Stans and Lawrence 2015). Surgical excision of the medial epicondylar fragment should be avoided because of poor reported long-term results (elbow pain, paresthesias along the medial border of the forearm and ulnar hand, sensation of instability of elbow) (Farsetti 2001).

The medial epicondyle serves as the attachment point for the ulnar collateral ligament as well as for the wrist flexor muscles. The ulnar collateral ligament is
recognized as the primary restraint for valgus force on the elbow. For this reason, concerns about symptomatic valgus instability have caused an increase in operative management of this fracture, even though no valgus instability (with a manual valgus stress test at 15° of flexion) was reported for 36 medial epicondyle fractures treated either with cast immobilization or open reduction and internal fixation (Farsetti 2001).

It has been suggested that operative treatment be performed more readily in athletic patients to prevent future instability problems (Gottschalk 2012 A, Stans and Lawrence 2015). However, in a two-year follow-up study of 20 athletes (six children treated nonoperatively [mean dislocation 5 mm evaluated from plain radiographs, no instability of elbow] and 14 treated operatively [mean dislocation 8 mm evaluated from plain radiographs, six with identified elbow dislocation]), excellent DASH scores were achieved in both groups. The authors suggested that nonoperative treatment in young athletes with low-energy medial epicondyle avulsions, a stable elbow, and minimal fracture displacement can be successful (Lawrence 2013).

2.4.5 COMPLICATIONS

Failure to recognize incarceration of the epicondylar fragment into the joint can result in a significant loss of elbow ROM, especially if it remains incarcerated for any length of time (Stans and Lawrence 2015). Louahem et al. (2010) reported stiffness of the elbow as a rare complication even after four weeks of immobilization in 139 operatively treated patients (two K-wires in 129 cases and one compressive screw in 10 cases).

The incidence of ulnar nerve injury varies from 10% to 16%. If the fragment is entrapped in the joint, the incidence may be as high as 50% (Stans and Lawrence 2015).

Reported symptoms of nonunion of medial epicondyle fracture include medial elbow pain, painful prominence at medial epicondyle, pain during activities, limited range of motion, valgus instability and ulnar nerve symptoms (Beck 2018). However, even though a considerable risk of nonunion in nonoperatively treated dislocated fractures has been reported (up to 90%), they are usually asymptomatic (Josefsson 1986, Beck 2018). In a long-term study of 139 operatively treated (two K-wires in 129 cases and one compressive screw in 10 cases) medial epicondyle fractures, union was achieved in all cases (nine fibrous unions) (Louahem 2010).
2.5 MEDIAL HUMERAL CONDYLE FRACTURE

2.5.1 EPIDEMIOLOGY AND CLASSIFICATION

Medial condyle fractures of the distal humerus are rare, accounting for less than 1% of fractures involving the distal humerus. Most of the patients are aged 8–14 years (Glotzbecker and Kasser 2015). Younger patients’ fractures tend to be undisplaced (Bensahel 1986). The trauma mechanism is falling on an outstretched arm with valgus twist or compression to the elbow in flexion and to the olecranon causes fracture of the medial condyle (Ghawabi 1975, Fowles 1980, Gonola 2006, Rang 2005).

Kilfoyle (1965) described three fracture patterns that can be helpful in determining the appropriate treatment. Type I: incomplete fracture that does not violate the joint surface but may hinge open. Type II: enters the joint but has <2 mm displacement. Type III: enters the joint and results in angulation deformity and malrotation.

2.5.2 SIGNS AND SYMPTOMS

Swelling is concentrated medially and there may be both varus and valgus instability of the elbow (Rang 2005, Gonola 2006, Glotzbecker and Kasser 2015). Ulnar nerve dysfunction may be present (Glotzbecker and Kasser 2015). Clinically and
on radiographs, a medial condylar fracture can be confused with a fracture of the medial epicondyle (Lee 2005).

### 2.5.3 Diagnosis

![Figure 13](https://via.placeholder.com/150)

*Figure 13. A coronal plane fracture radiograph of a medial humeral condyle fracture in an 8-year-old boy.*

Diagnosis can be challenging, especially if the fracture occurs before the ossification center of the trochlea appears (Rang 2005, Gonola 2006). Isolated fractures of the medial epicondyle are extra-articular and usually do not have positive fat-pad signs compared to medial condyle fractures with a positive fat-pad sign (Harrison 1984). In older children with a large metaphyseal fragment, involvement of the entire condyle is usually obvious on radiographs (Glotzbecker and Kasser 2015).

If the diagnosis is unclear in a child younger than 8–10 years of age with significant medial elbow ecchymosis, arthrography or MRI of the elbow should be performed (Glotzbecker and Kasser 2015).

### 2.5.4 Treatment

Kilfoyle type I and II fractures can be treated nonoperatively with cast immobilization (Papavasiliou 1987). The fracture union time is longer compared to extra-articular distal humerus fractures in children (Gonola 2006). For displaced fractures, open reduction and internal fixation is the treatment method used most often (Ghawabi 1975, Bensahel 1986, Papavasiliou 1987).
2.5.5 COMPLICATIONS

Untreated displaced fractures usually result in nonunion with cubitus varus deformity (Gonola 2006, Glotzbecker and Kasser 2015). Valgus deformities have also been reported (as a secondary stimulation of overgrowth of the medial condylar fragment) (Glotzbecker Kasser 2015). If the fracture line disrupts the blood supply to the lateral ossification center of the medial aspect of the trochlea, a fishtail deformity may develop (Gonola 2006, Glotzbecker Kasser 2015).

2.6 LATERAL HUMERAL EPICONDYLE FRACTURE

2.6.1 EPIDEMIOLOGY

Fractures of the lateral epicondyle are extremely rare and most of them occur in children over 10 years of age (Rang 2005, Gonola 2006).

In adults, the most common etiology is a direct blow to the lateral side of the elbow. In children, it is believed that an avulsion force of the forearm extensor muscles may be responsible for some of these fractures (Glotzbecker and Kasser 2015).

2.6.2 SIGNS AND SYMPTOMS

The symptoms of a lateral humeral epicondyle fracture are elbow swelling and pain on the lateral aspect of the distal humerus (Glotzbecker and Kasser 2015).
2.6.3 DIAGNOSIS

Figure 15. A coronal plane radiograph of a lateral humeral epicondylar fracture in a 9-year-old boy.

Fractures can often be confused with normal anatomy of the lateral epicondyle. The distal part of the epiphysis fuses with the capitellum before the proximal part unites with the adjacent humerus. This frequently results in the physis appearing like a fracture. Radiographs of the uninjured elbow can be helpful (Silberstein 1982).

2.6.4 TREATMENT

Unless the fragment is incarcerated within the joint, treatment usually consists of simple immobilization for comfort, until mobilization is tolerated. (McLeod 1993, Rang 2005, Gonola 2006, Glotzbecker and Kasser 2015).

2.6.5 COMPLICATIONS

Although nonunion of fracture can occur, it usually does not affect elbow function (Glotzbecker Kasser 2015). Displacement >5 mm may cause elbow stiffness, and treatment by fragment excision has been suggested (Rang 2005, Gonola 2006).
3 AIMS OF THE PRESENT STUDY

SCHF is the most commonly operatively treated fracture in children. The incidence of fracture- and treatment-related injuries is higher than in other pediatric fractures. Fracture reduction and pin fixation can be challenging, especially in inexperienced hands. Follow-up protocols are based on tradition. The long-term subjective outcome of pin-fixed SCHF has not been well assessed.

The aims of this study are:
1. to assess the effect on treatment outcome of postponing pin fixation of SCHF without compromised blood circulation to office hours;
2. to evaluate whether postoperative radiographs are needed after pin fixation of SCHF;
3. to assess the quality of treatment of pediatric distal humerus fractures in Finland;
4. to determine the objective and subjective long-term outcome of pin-fixed SCHF in the Children’s Hospital, Helsinki.

Our objective is to formulate national guidance for pin fixation of SCHF in children based on our study conclusions.
4 PATIENTS AND METHODS

4.1 POSTPONING OPERATIVE TREATMENT OF SCHF (I)

Two hundred children with pin-fixed SCHF, treated consecutive in the Children’s Hospital, Helsinki between June 2002 and March 2007, were included. The first 100 patients were treated before November 2004 (group A), after which night-time (midnight to 7.00 a.m.) surgery was permitted only for patients with compromised distal blood circulation (group B).

The average age of the children at surgery was 7.1 years (range 1.8–14.1). Boys accounted for 107 (54%) of the children and 108 (54%) were left-sided. The most common trauma mechanisms were falling from a height (53%), sporting activities (31%) and falling on a level surface (15%). Three children had sustained a high-energy trauma, and the etiology of the fracture was unknown in two. Nearly all (99%) fractures were extension-type injuries (Gartland III 83.5%, Gartland II 15.5%). Eight children had an open fracture (five before the new regulation and three after it).

There was no difference between the two patient groups regarding sex (p=0.77), age (number of patients younger or older than 10 years; p=0.45), trauma mechanism (p=0.36–1.00) or number of open fractures (five in group A, three in group B; p=0.72). Slightly more children had sustained a grade II fracture in group A than in group B (p=0.12).

The number of different consultants (board-qualified orthopedic surgeon, number of operations 7–30) and registrars (in the final three years of six years of training to become either an orthopedic or a pediatric surgeon, number of operations 1–21) performing surgery was eight and 26 in group A and nine and 21 in group B.

There was one child in group A that had her brachial artery explored and another child in group B that had a brachial artery reconstruction with a synthetic graft emergently. No Volkmann’s contracture developed. The rate of nerve injury was similar in both patient groups (p=0.26) (Table 3).

Surgery was commenced during office hours (8.00 a.m. to 3.00 p.m.) in 27% (group A) vs 55% (group B) of the children (p<0.0001). The length of time from admission to surgery exceeded six hours in 25% (group A) vs 52% (group B) of the children (p<0.0001). The number of operations performed during weekends was the same in both treatment groups. Night-time procedures (midnight to 7.00 a.m.) decreased from 12% (group A) to 2% (group B) after the new regulation (p=0.01).

All available radiographs were analyzed by a pediatric radiologist (RK) and an orthopedic registrar (NT) (87 patients in group A [seven children lacked postoperative radiographs and for six the radiographs were unusable for radiographic parameter
measurements] and 90 patients in group B [seven children lacked postoperative radiographs and for three the radiographs were unusable for radiographic parameter measurements]). The quality of the osteosynthesis was evaluated by analyzing the number of pins fixing both fracture fragments and their configuration (pins should not cross at fracture level). Radiographic alignment was considered satisfactory at fracture union if the BA was within ±10° of the reported normal range and the AHL crossed the capitellum with no malrotation.

### 4.2 RADIOGRAPHIC FOLLOW-UP (II)

Operatively treated Gartland grade III and flexion-type SCHFs from two separate study periods (167 children from 2002 to 2006 and 97 from 2012 to 2014) were involved in this study (Figure 16). The study was planned after we realized, during assessment of the long-term outcome of SCHFs treated at our institution between 2002 and 2006, that postoperative radiographs had little value in clinical decision making. During the later study period (2012–2014), an instruction was given that postoperative radiographs should not be taken after clinically stable pin fixation in cases of satisfactory alignment. A follow-up visit for pin removal 3–4 weeks after the fracture was scheduled, in contrast to the earlier study period (2002–2006), when follow-up visits with radiographs at one week and at pin removal were routine.

**Figure 16.** Pin fixed supracondylar humerus fractures in the Children’s Hospital, Helsinki

Of the 264 children (median age 6.8 years [range 1.4–14.1]), 161 (61%) were boys. Thirteen children (5%) had an open fracture. Seventeen consultants performed
PATIENTS AND METHODS

188 operations (median 11 [range 1–26]) and 35 orthopedic or pediatric surgical registrars performed 76 operations (median 2 [range 1–8]).

All available radiographs and stored fluoroscopic images were analyzed by a pediatric radiologist (RK) and an orthopedic registrar (NT). Fracture alignment was assessed by measuring BA, LCHA and the AHL crossing point with the capitellum. The intersection point of the AHL with the ossification center of the capitellum was measured and divided into five zones (Figure 17). Rotatory alignment was analyzed on radiographs and on stored fluoroscopic images by assessing the symmetry of reduction of the medial and lateral columns. Malrotation was registered if reduction was asymmetric but its degree could not be measured. The quality of the osteosynthesis was evaluated by analyzing the purchase, number and configuration of the pins. Fracture alignment was analyzed from postoperative radiographs except for 34 patients treated during the second study period who did not have any postoperative radiographs taken.

![Figure 17. The intersection point of the anterior humeral line with the ossification center of the capitellum divided into five different zones.](image)

The Baumann angle and LCHA were recorded as an average of the two separate measurements performed by the RK and NT. Inter- and intra-observer reliability of the Baumann angle and LCHA was calculated using a Pearson correlation coefficient (Silva et al. 2010).

Reduction pattern (open vs closed) and complications (nerve injuries, pin track infections) were registered. The time and setting of pin removal were assessed. The number of corrective osteotomies was calculated. Patients were followed up until satisfactory subjective recovery of CA, ROM and hand function. Patient satisfaction
was assessed with a questionnaire regarding the appearance and functional outcome, conducted by mail or phone at a minimum of one-year follow-up. Children or their parents assessed elbow ROM (extension and flexion) and CA (symmetrical or asymmetrical).

The children operated on in each of the two time periods, 2002–2006 and 2012–2014, were compared with regard to the quality of reduction and pin fixation. The children operated on by consultants were compared to those operated on by registrars with regard to the quality of reduction and pin fixation.

4.3 QUALITY OF TREATMENT OF DISTAL HUMERUS FRACTURES IN FINLAND (III)

Data concerning distal humerus fractures (International Classification of Diseases ICD-9 or ICD-10 diagnosis codes 812.4, 812.5 and 42.4) in children under 17 years of age were obtained from the Care Register for Health Care (HILMO). National data on the activities of health centers, hospitals and other institutions that provide inpatient care are collected by this registry. The number of patients who were treated for distal humerus fracture (including ICD-9 or ICD-10 operation codes 9123, 9126, 9128, 9112, NBJ41, NBJ64 and NBK30) was recorded from 1990 to 2010. As all distal humeral fractures are registered with the same codes (ICD-9 and ICD-10), registry-based distinction between different fracture types was impossible.

All claims filed by the Patient Insurance Centre (PIC) concerning distal humerus fractures in children under 17 years of age during the study period were retrospectively analyzed. The child’s age at the time of the injury and trauma mechanism were registered. Type of treatment, complications and reoperations were registered. An independent expert retrospectively blindly analyzed all decisions made by the PIC. A medical advisor working for the PIC also re-evaluated the cases without knowing the decisions made by the PIC.

The risk of a compensated treatment injury was evaluated for different treatment institutions. The average amount of compensation per patient was calculated.
4.4 LONG-TERM OUTCOME OF PIN-FIXED SCHF IN THE CHILDREN´S HOSPITAL, HELSINKI (IV)

A total of 210 domestic pin-fixed children with a SCHF from the five-year study period 2002–2006 were invited to participate in the study (Figure 18). The study period was partly the same as for the study of postponing operative treatment of SCHF. Of these children, 115 (55%) were boys, and 133 (63%) fractures were left-sided. Mean age at the time of fracture was 7.2 years (range 1.8–14.1). The trauma mechanisms were falling from a height in 53% of the fractures, sporting activities in 30% and falling on level surface in 15%. Ten (5%) of the fractures were open. The main surgeon was a consultant in 60 (29%) cases (eight consultants, mean number of operations per surgeon: 8 [range 2–19]) and a registrar in 150 (71%) cases (31 registrars, mean number of operations per surgeon: 5 [range 1–20]). Registrars performed 59 (28%) operations alone without consultant supervision.

Fourteen (7%) children had open reduction (anterior 11, lateral two, medial and lateral approach one). Osteosynthesis was performed through small skin incisions percutaneously with crossed pins in 200 children and with lateral pins in 10 patients. The brachial artery of one child was repaired. Volkmann’s contracture did not develop in any of our patients. Two children had a primary operation performed by a registrar alone and were reoperated on within a week because of unsatisfactory primary reduction. Three children had their primary operation elsewhere and were reoperated on in our institution within a week because of unsatisfactory primary reduction. One child had a deep infection and an additional seven children (together 4%) had a superficial pin-track infection. Corrective osteotomy was performed for

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**Figure 18.** Operatively treated supracondylar humerus fractures 2002-2006. Patients’ participation in the study and fracture types according to the Gartland classification.
two children (primarily operated on by a registrar) due to gun-stock deformity three and eight years after the fracture.

A total of 36 (22%) of the 166 children with Gartland III fractures had clinical findings of either median (19), ulnar (seven), radial (seven) or median and ulnar (three) nerve injury at discharge (even minor findings were recorded). Normal motor and sensory findings were recorded in 13 of these 36 children preoperatively (one median and ulnar, three ulnar, three radial and six median nerve palsies). Electromyography (EMG) was carried out on 18 (11%) of these children with no (11) or partial recovery within 3–6 months. One child’s (primarily treated by a consultant) median nerve was found to be partially entrapped in the fracture gap, and released and repaired with subtotal recovery one year after fracture. All the other children’s sensomotor functions recovered. The permanent nerve injury rate as a complication of treatment was thus 0.4%.

Postoperative radiographs of 197 (94%) children were analysed by a pediatric radiologist and an orthopedic registrar. At fracture union, alignment was regarded satisfactory (BA within ±10° of reported normal range and AHL crossed capitellum) in 150/184 (82%) of the children’s radiographs (13 children had either undiagnostic sagittal or coronal view radiographs). Grade II fractures healed in better alignment than grade III fractures (satisfactory result in 27/28 vs 121/152, p=0.03). The intra-(r= 0.91 and 0.91) and inter-observer (r=0.92) reliability of the Baumann angle measurement were considered excellent (Pearson correlation coefficient).

After a mean follow-up of nine (range 7–12) years, 80% (n=168) of the children answered a questionnaire regarding the appearance, function and pain (scale 0–10) of the fractured elbow and the symmetry of ROM and CA of their elbows (Table 2). The proportion of children who also attended a clinical examination performed by an NT was 31% (n=65). ROM and CA of both elbows were measured with a goniometer. Radiographs of both elbows were taken if asymmetry in ROM or CA exceeded 10°. The lengths of both arms were measured from the tip of the acromion to the distal end of the lateral humeral condyle, and of the forearms from the tip of the olecranon to the distal end of the ulna.
PATIENTS AND METHODS

Table 2. Questionnaire.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Answer options</th>
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<tbody>
<tr>
<td>1. How satisfied are you with the appearance of the fractured elbow?</td>
<td>0–10 very unsatisfied – very satisfied</td>
</tr>
<tr>
<td>2. How satisfied are you with the functional outcome of the fractured elbow?</td>
<td>0–10 very unsatisfied – very satisfied</td>
</tr>
<tr>
<td>3. Do you have any pain in rest in the fractured elbow?</td>
<td>no/yes</td>
</tr>
<tr>
<td>If you answered yes, how intense has the pain been in the past week?</td>
<td>0–10 no pain – worst pain you can imagine</td>
</tr>
<tr>
<td>4. Do you have any pain in motion in the fractured elbow?</td>
<td>no/yes</td>
</tr>
<tr>
<td>If you answered yes, how intense has the pain been in the past week?</td>
<td>0–10 no pain – worst pain you can imagine</td>
</tr>
<tr>
<td>5. Are carrying angles of your elbows symmetrical?</td>
<td>no/yes</td>
</tr>
<tr>
<td>6. Do your elbows flex symmetrically?</td>
<td>no/yes</td>
</tr>
<tr>
<td>7. Do your elbows extend symmetrically?</td>
<td>no/yes</td>
</tr>
</tbody>
</table>

Of the 42 children who did not participate in this study, 12 had postoperative follow-up elsewhere, 16 had no further controls after pin removal, four were followed up after 6–12 weeks to ensure fracture union and recovery of elbow motion, and one was followed up until five years because of valgus deformity. The remaining nine children who did not answer the questionnaire were seen regularly until satisfactory recovery of their nerve palsy (mean follow-up six months [range 1 month – 2 years]).

There was no difference in radiological outcome at union between children who answered only the questionnaire and those that also attended the clinical follow-up examination or between children who participated in the study and those that did not.

4.5 STATISTICS

Statistical analysis was performed using Fisher’s exact test and the Wilcoxon test. P values ≤0.05 are considered statistically significant.

4.6 ETHICAL CONSIDERATIONS

The Ethics Board of Helsinki University Central Hospital approved the study protocol (approval identification number: 346/13/03/03/2012). The participants took part in the study voluntarily. Informed written consent to participate was obtained from the long-term outcome patients. Patients were guided to the appropriate treatment when needed. Patients were informed that the information collected would be used for medical research purposes and they were provided with a summary of the results.
5  RESULTS

5.1  POSTPONING OPERATIVE TREATMENT OF SCHF (I)

Open reduction was performed on eight group A children and 11 group B children (p=0.63). The proportion of operations performed alone by a registrar dropped from 39% to 14% after intervention in the treatment protocol was initiated in November 2004. On the other hand, the proportion of operations performed by a consultant with a registrar present increased from 51% to 73% and the number of operations performed by a consultant as the main surgeon increased from 27% to 43% (p=0.02). Of the fractures operated on by a registrar alone and with a consultant’s assistance, 12/30 and 8/80 were Gartland grade II (p=0.008).

Mean operating room time (including reduction, pin fixation and casting) decreased by 11 minutes from 54 (range 15–147) minutes in group A to 44 (range 14–170) minutes in group B (two children with vascular operations that lasted 228 and 175 minutes were excluded from this calculation). The sum of the operation times was 16.5 hours greater in group A than in group B (93 hours 36 minutes vs 77 hours 8 minutes). The amount of experience of the main surgeon had no impact on the mean operating room time (registrars’ mean operation time 50 minutes (range 15–170 minutes) consultant mean operation time 46 minutes (range 14–143 minutes [p=0.24])). The number of operations lasting less than 60 minutes increased from 67 to 84 after the new regulation (p=0.008). The number of operations lasting over 120 minutes decreased from nine to three after the new regulation (p=0.14).

Re-reduction was necessary because of unsatisfactory fracture alignment in one child with a Gartland grade II fracture operated on by a registrar at 8.00 p.m. in group A (p=1.00) (Table 3). One deep infection in group A was treated with revision surgery, and this child with a closed Gartland grade III fracture was operated on by a registrar at 6.00 p.m. Superficial pin tract infections that healed uneventfully with per oral antibiotics were recorded in seven additional children (four in group A and three in group B) (Table 3).

The rate of children with radiologically stable pin fixation (two or more pins not crossing at the fracture line, puncturing both fracture fragments) increased from 42% (group A) to 55% (group B) (p=0.08). Partial loss of reduction was observed in five children (four in group A, one in group B) with no further treatment. At fracture union, radiographic alignment was satisfactory in 68% of children in both groups (59/87 and 61/90). No difference between the groups was noticed regarding the BA within ±10° of the reported normal range (82% [group A] vs 84% [group B]; p=0.85), the proportion of children with the AHL crossing the capitellum (82% in both
RESULTS

groups) or the proportion of children that had no rotation evident on radiographs (77% [group A] vs 76% [group B]; p=0.70) (Table 3).

One verified iatrogenic nerve injury was diagnosed in each group (Table 3). In group A, one child’s ulnar nerve was found pierced and partially lacerated by a K-wire. In group B, one child’s median nerve was found partially entrapped in the fracture gap, and was released and repaired with partial recovery. Both these children were operated on during office hours with a consultant orthopedic surgeon attending.

One varus deformity was corrected by osteotomy in each group (Table 3). Of these, the group A patient’s fracture was operated on by a registrar alone and the group B patient was operated on by a registrar and consultant together.
Table 3. A comparison of the findings from group A (children before postponing operative treatment of supracondylar humerus fractures to office hours, n=100) and group B (after postponing operative treatment, n=100) children.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Group A</th>
<th>Group B</th>
<th>p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gartland II</td>
<td>20</td>
<td>11</td>
<td>0.12</td>
</tr>
<tr>
<td>Gartland III</td>
<td>79</td>
<td>88</td>
<td>0.13</td>
</tr>
<tr>
<td>Flexion</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>Open reduction</td>
<td>8</td>
<td>11</td>
<td>0.63</td>
</tr>
<tr>
<td>Number of pin(s) crossing both fracture fragments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥2 stable</td>
<td>39</td>
<td>52</td>
<td>0.08</td>
</tr>
<tr>
<td>≥2 unstable</td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>42</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>7</td>
<td>9</td>
<td>1.00</td>
</tr>
<tr>
<td>unknown</td>
<td>7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Baumann angle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>79</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>normal</td>
<td>55</td>
<td>70</td>
<td>0.07</td>
</tr>
<tr>
<td>&gt;10° abnormality</td>
<td>5</td>
<td>6</td>
<td>1.00</td>
</tr>
<tr>
<td>unknown</td>
<td>13</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>AHL crossing with the capitellum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no</td>
<td>11</td>
<td>12</td>
<td>1.00</td>
</tr>
<tr>
<td>yes</td>
<td>82</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>unknown</td>
<td>7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Rotation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yes</td>
<td>15</td>
<td>18</td>
<td>0.70</td>
</tr>
<tr>
<td>no</td>
<td>77</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>unknown</td>
<td>8</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Hospital days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>1.2</td>
<td>range 0–7</td>
<td>1.3   range 0–5</td>
</tr>
<tr>
<td>Fracture complications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nerve injury</td>
<td>14</td>
<td>21</td>
<td>0.26</td>
</tr>
<tr>
<td>median</td>
<td>8</td>
<td>5 preoperatively</td>
<td>11</td>
</tr>
<tr>
<td>ulnar</td>
<td>6</td>
<td>2 preoperatively</td>
<td>4</td>
</tr>
<tr>
<td>radial</td>
<td>3</td>
<td>5 preoperatively</td>
<td>5</td>
</tr>
<tr>
<td>vascular injury</td>
<td>1 brachial artery exploration</td>
<td>1 brachial artery repair</td>
<td>1.00</td>
</tr>
<tr>
<td>Complication of treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nerve injury</td>
<td>1 partial median nerve repair</td>
<td>1 ulnar nerve exploration</td>
<td>1.00</td>
</tr>
<tr>
<td>unsatisfactory reduction</td>
<td></td>
<td></td>
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<tr>
<td>re-reduction</td>
<td>1</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>corrective osteotomy</td>
<td>1 varus deformity</td>
<td>1 varus deformity</td>
<td>1.00</td>
</tr>
<tr>
<td>infection</td>
<td>5 1 deep infection</td>
<td>3</td>
<td>0.72</td>
</tr>
</tbody>
</table>
5.2 RADIOGRAPHIC FOLLOW-UP (II)

A total of 426 postoperative radiographs and 90 intraoperative stored fluoroscopic images were analyzed. The median number of postoperative radiographs per child was two (range 1–7) in 2002–2006 and one (range 0–3) in 2012–2014 (Table 4 and Table 5).

Table 4. The number of patients and the number of postoperative radiographs per patient.

<table>
<thead>
<tr>
<th>year</th>
<th>patients (n)</th>
<th>postoperative radiographs (n) per patient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>2003</td>
<td>32</td>
<td>0</td>
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<tr>
<td>2004</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>2005</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>34</td>
<td>6</td>
</tr>
<tr>
<td>2013</td>
<td>33</td>
<td>7</td>
</tr>
<tr>
<td>2014</td>
<td>30</td>
<td>21</td>
</tr>
</tbody>
</table>

Table 5. The timing of postoperative radiographs.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>before discharge</td>
<td>46</td>
<td>5</td>
</tr>
<tr>
<td>after discharge &lt;3 weeks</td>
<td>61</td>
<td>24</td>
</tr>
<tr>
<td>3–6 weeks</td>
<td>167</td>
<td>52</td>
</tr>
<tr>
<td>&gt;6 weeks &lt;1 year</td>
<td>56</td>
<td>5</td>
</tr>
<tr>
<td>&gt;1 year</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

The Baumann angle (median 77°, range 49°–105°) was within the normal range in 174 of the 264 children (66%), less than 10° outside the normal range in 57 (22%), more than 10° outside the normal range in 12 (5%) and unmeasurable in 21 (8%) children because of closed growth plates (11/21) or inadequate coronal plane radiographs (10/21). The percentage of patients having a Baumann angle more than 10° outside the normal range was greater in children operated on in 2002–2006 (7% vs 1%) (p=0.06). The intra- (r= 0.91 and 0.91) and inter-observer (r=0.92) reliability were considered excellent.

The LCHA (median 53°, range 26°–93°) was within the normal range in 106 (40%) children, less than 10° outside the normal range in 95 (36%), more than 10° outside the normal range in 30 (11%) and unmeasurable in 33 (13%) because of inadequate sagittal plane radiographs (22/33) or closed growth plates (11/33). The intra- (r= 0.80 and 0.84) and inter-observer (r=0.83) reliability were considered good.
The AHL crossed the ossification center of the capitellum in 223 (84%) children, bypassed it in 37 (14%) and could not be recorded in four children (Table 6). The proportion of children with the AHL bypassing the ossification center decreased from 15% during 2002–2006 to 13% during 2012–2014 (p=0.71). There was disagreement between the observers in 16 cases about the exact zone (anterior, middle or posterior) at which the AHL crossed the bony capitellum. Rotatory malaligment was seen in 39 (15%) patients and could not be registered in two children. The incidence of malrotation diminished from 17% during 2002–2006 to 10% during 2012–2014 (p=0.15) (Figure 19).

**Table 6.** The intersection point of anterior humeral line with the ossification center of capitellum in five different zones.

<table>
<thead>
<tr>
<th>AHL intersection point with capitellum</th>
<th>2002–2006 (n=166)</th>
<th>2012–2014 (n=94)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>-1</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>0</td>
<td>86</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>5</td>
</tr>
</tbody>
</table>

**Figure 19.** Quality of reduction of pediatric supracondylar humerus fracture patients (n=264). Satisfactory alignment (green), unsatisfactory alignment (yellow and red) and 10° outside normal values (red).
RESULTS

Fractures were fixed with two pins in 195 (74%) children, three pins in 63 (24%), four pins in five (2%) and five pins in one child respectively. Crossed pins were used in 235 (89%) and unilateral pins in 29 (11%) fractures. Two or more pins fixed both fracture fragments in 171 (65%) children. Pin fixation was unsatisfactory in 88 (33%) children (one proper pin in 69 children, zero proper pins in 19 patients). Pin purchase could not be assessed in five children’s radiographs.

Reduction was somewhat compromised during follow-up in 10 children. This was because of inadequate pin fixation of the medial column in nine children, of which three also had unsatisfactory reduction of the fracture (malrotation). One child’s pins were accidentally removed seven days after surgery, but the Baumann angle remained normal and the AHL crossed the capitellum. One child’s Baumann angle was >10° outside the normal range and the AHL did not cross the capitellum, leading to a 15° extension deficit and 4° cubitus varus deformity, but the child was fully satisfied with the functional and cosmetic outcome. One child’s AHL did not cross the capitellum but normal elbow range of motion was restored despite this. The remaining seven children’s Baumann angle was <10° outside the normal range and the AHL crossed the capitellum. None of them wanted to have any further surgery. The rate of satisfactory pin fixation increased from 53% in 2002–2006 to 85% in 2012–2014.

Fracture alignment worsened during radiographic follow-up in 8/188 children operated on by consultants compared to 2/76 children operated on by registrars. Six children treated by a consultant had pin track infections that healed uneventfully with antibiotics.

Pin removal was performed at median 27 days (range 7–49) in 2002–2006 and at median 25 days (range 18–36) in 2012–2014. Anesthesia was required either because of a pin buried under the skin or patient discomfort in 19 (8%) children, of which 16 belonged to the earlier study period in 2002–2006. In four children, pin removal was postponed because delayed healing was suspected in radiographs. Retrospectively analyzed, all these fractures were radiologically healed and pins could have been removed as planned.

Follow-up ranged from seven to 12 years in 135 of the 167 children (81%) treated in 2002–2006 and from one to four years in 94 of 97 the children (97%) from 2012–2014. The quality of reduction was similar in both patient groups who were followed up and those who were not. Of the 229 children (87%) with at least one year of follow-up, 185 (81%) had symmetrical extension, 212 (93%) had symmetrical flexion and 194 (85%) had symmetrical CA. None of these children reported functional disability of the fractured elbow and none had received further treatment, except for one child who had a corrective osteotomy. This child’s primary reduction and pin fixation was unsatisfactory and he would have been better treated by reoperation the next day (Figure 20).
Of the 32 children treated in 2002–2006 with no long-term follow-up, 10 had clinical check-ups 2–30 months after operation due to restricted elbow ROM (six children) or nerve palsy (four children). One of the four children with nerve palsy had partial laceration of the ulnar nerve caused by the ulnar fixation pin, which was removed two days after the primary operation. Another child’s median nerve had been entrapped between fracture fragments, and exploration and partial nerve repair was performed. Seventeen children had no follow-up and could not be contacted after pin removal. Five other children who had follow-up elsewhere after pin fixation at our institution could not be contacted. Three children treated during the second study period could not be contacted after treatment at our institution. Two out of three patients with treatment complications were operated on by a consultant.

5.3 QUALITY OF TREATMENT OF DISTAL HUMERUS FRACTURES IN FINLAND (III)

According to HILMO, 7,909 children under the age of 17 had a distal humerus fracture treated under anesthesia in 61 different institutions during the study period 1990–2010. Retention of the fracture was performed by immobilization in 1,667 and by internal fixation in 5,859. The rest (383) patients had some other kind of operation (such as nerve exploration, thromboembolectomy or fracture treatment by traction). During the study period, 72 corrective osteotomies of the distal humerus were performed.

During the study period, 133 compensation claims were filed for 117 children (118 fractures). One compensation claim could include multiple issues. The average age at injury was eight years (1–15). The trauma energy was considered low in 19
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(16%), moderate in 94 (80%), high in two (2%) and unknown in three (3%) fractures. One of the fractures was an open fracture, five were polytraumas (four associated upper limb fractures and one head contusion) and four were fracture dislocations. The mean delay from injury to claim was two (range 0–12) years.

Compensation was granted in 34/46 claims directed to university hospitals, 35/48 to central hospitals, 16/19 to district hospitals, 6/16 to healthcare centers, 2/3 to private clinics and 0/1 to the ambulance service. The rate of compensated treatment complication in patients varied between treatment institutions at different levels: 0.8% in university hospitals; 1.2% in central hospitals; 2.3% in district hospitals; 10.0% in private clinics and 13.6% in healthcare centers. There was a threefold difference in the risk of treatment complication between the university hospitals with the lowest and highest risk (0.5–1.5%) (Figures 21 and 22). The national risk of a compensated treatment complication was 1.1%. To date, the average amount of compensation per patient has been €3 500 (€200–15 054).

Figure 21. The risk of treatment complication for pediatric distal humeral fractures in Finland from 1990 to 2010 by type of treatment institution (secondary and tertiary hospitals). The range of the number of patients treated by hospital type is given in parentheses.
The risk of complication of treatment for pediatric distal humeral fractures at institutions of differing levels in Finland from 1990 through 2010 by subtype of complication (delayed treatment, nerve injury and deformity). Treatment institutions are divided into three groups on the basis of the mean number of patients treated annually.

The PIC used 19 medical advisors (five pediatric orthopedic surgeons for a total of 42 cases; nine orthopedic surgeons for a total of 53 cases; two hand surgeons for a total of 18 cases; two general practitioners for a total of three cases), each of whom evaluated 1–24 patient claims. After re-evaluating all the claims and decisions, the independent expert (AS) and the PIC medical advisor (YN) disagreed with the PIC decision regarding 15 (13%) of the fractures: they believed that compensation had been wrongly denied for 12 and that unjustified compensation had been granted for three. AS and YN disagreed with the pediatric orthopedic surgeons in 4/42 cases, with the orthopedic surgeons in 7/53 cases, with the hand surgeons in 3/18 cases and with the general practitioners in 1/3 cases. The highest rate of discrepancy between the re-evaluators and a single expert medical adviser was 4/14.

On the basis of the re-evaluation of all compensation claims, 90 patients experienced treatment complications (59 supracondylar, 12 lateral condylar, nine medial epicondylar, five T-type, three lateral epicondylar and two medial condylar fractures) (Table 7).

Missed diagnosis: Nine fractures were initially missed (four supracondylar fractures, one lateral condyle fracture, two medial epicondyle fractures, one lateral epicondyle fracture and one medial condyle fracture). Eight of these fractures were later treated with cast immobilization and one of the missed medial epicondyle fractures with percutaneous pinning. No deformity was diagnosed.
RESULTS

Delayed treatment: Appropriate treatment was delayed in eight lateral condyle, six supracondylar, two medial epicondyle, two lateral epicondyle and two T-type fractures. Treatment was changed from cast or collar and cuff immobilization to operative treatment in all except two cases (one lateral condyle and one lateral epicondyle) in which the delay for consultation and consideration of operative treatment was considered too long (two weeks).

Nerve injuries: Iatrogenic nerve injuries occurred in 17 operatively treated supracondylar fractures and one medial condyle fracture. Four patients with a supracondylar fracture had an early reoperation due to suspected iatrogenic ulnar nerve injury (two medial pin removals, two explorations and re-manipulations). Late nerve explorations were performed in another four supracondylar fracture patients 1–122 months after initial injury (two ulnar nerves, one radial nerve, one including both ulnar and radial nerves). Nerve injuries were considered permanent in four cases (all supracondylar fractures). A permanent disability compensation of 5% was granted for three patients and of 10% for one patient.

Nonunion: Nonunion of the fracture was treated surgically in eight children who had a lateral condyle fracture. The primary treatment was cast immobilization in five of the children. Two patients were pin fixed, with one having a postoperative infection. One patient’s primary treatment was performed in a private clinic without proper patient records. This child’s nonunion was operated on twice – the immobilization time after the first operation was considered too short without union of the fracture.

Deformity: Reoperations due to unsatisfactory fracture alignment were performed in 12 supracondylar fractures (one patient had two reoperations), one T-type fracture and one lateral condyle fracture. Deformity was corrected by osteotomy in 22 patients with supracondylar fracture and in one patient with a lateral condyle fracture. Five of the 23 patients were operated on at least twice before the result was satisfactory. Seven of these patients were primarily treated with cast immobilization without manipulation, eight with manipulation under anesthesia and cast immobilization and seven with percutaneous pin fixation.

In our opinion, most treatment complications (86/90) could have been avoided: 13 by correct primary diagnosis, 28 by reducing an unacceptable primary fracture alignment and 43 by a satisfactory standard of operative treatment. One patient sustained a wound during cast removal, leaving a minor scar. One patient fainted when removing the cast and injured a tooth. Most of the unavoidable complications from treatment were infections (10 of the claims concerned infections).
Table 7. Reasons for claims and granted compensation for pediatric distal humeral fractures in Finland (1990–2010).

5.4 LONG-TERM OUTCOME OF PIN-FIXED SCHF IN THE CHILDREN’S HOSPITAL, HELSINKI (IV)

The mean subjective score for appearance was 8.7 (range 2–10) and for function 9.0 (range 2–10) according to the 168 answered questionnaires (Table 8). The fracture type, the sex of the patient and the AHL in relation to the capitellum did not affect the results. The mean functional scores were lower in 31 children who were >10 years old at the time of fracture (8.4, p=0.01) and in 29/36 children who had nerve injuries (8.6, p=0.05). The mean appearance scores were lower in 14 children who had open reduction (7.8, p=0.03) and in nine patients who had BA values exceeding the normal values by 10˚ (7.1, p=0.02) (Figure 23). Open reduction patients’ AHL crossed the capitellum in 11/12 cases and the BA was within 10˚ of the normal range in 11/12 cases. One or both subjective scores of 13 (8%) patients were below six. Eight of these 13 patients attended a control visit, and five of them had asymmetry of elbow ROM or CA or both exceeding 10˚ (p=0.002). Eleven of
RESULTS

des these 13 children were operated on by a registrar (five with the registrar alone, six under supervision) (p=0.36).

Table 8. Questionnaire and answers (n=168 patients).

<table>
<thead>
<tr>
<th>Questions</th>
<th>Answers options</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How satisfied are you with the appearance of the fractured elbow?</td>
<td>0–10 very unsatisfied - very satisfied</td>
<td>8.7 range 2–10</td>
</tr>
<tr>
<td>2. How satisfied are you with the functional outcome of the fractured elbow?</td>
<td>0–10 very unsatisfied - very satisfied</td>
<td>9 range 2–10</td>
</tr>
<tr>
<td>3. Do you have any pain in rest in the fractured elbow?</td>
<td>no/yes</td>
<td>7</td>
</tr>
<tr>
<td>If you answered yes, how intense has the pain been in the past week?</td>
<td>0–10 no pain - worst pain you can imagine</td>
<td>3 range 1–8</td>
</tr>
<tr>
<td>4. Do you have any pain in motion in the fractured elbow?</td>
<td>no/yes</td>
<td>21</td>
</tr>
<tr>
<td>If you answered yes, how intense has the pain been in the past week?</td>
<td>0–10 no pain - worst pain you can imagine</td>
<td>3.9 range 1–8</td>
</tr>
<tr>
<td>5. Are carrying angles of your elbows symmetrical?</td>
<td>no/yes</td>
<td>140</td>
</tr>
<tr>
<td>6. Do your elbows flex symmetrically?</td>
<td>no/yes</td>
<td>149</td>
</tr>
<tr>
<td>7. Do your elbows extend symmetrically?</td>
<td>no/yes</td>
<td>132</td>
</tr>
</tbody>
</table>

Figure 23. Subjective cosmetic result correlated with Baumann angle (BA) at fracture union (n=141).

Elbow pain either at rest (PAR) or in motion (PIM) or both was reported by 14% (n=168): PIM by 13% (median 4 [1–8]) and PAR by 4% (median 2.5 [1–8]). Pain was not related to fracture type or sex, but was more common in children with nerve injury (8/29, p=0.04), in children >10 years of age at the time of injury (7/31,
p=0.16), in children with elbow flexion deficit (>10°; 2/4, p=0.20) and in children with elbow CA asymmetry exceeding 10° to varus (3/9, p=0.39).

Asymmetric elbow ROM was reported by 28% (extension 21%, flexion 11%) and CA by 17% (n=168) of the children (Table 9). Fracture type or radiographic findings at the fracture union did not affect the results, but asymmetric elbow ROM was more frequently experienced by girls (girls 29/75 vs boys 18/93, p=0.01). Subjective assessment of elbow ROM and CA of the control visit patients proved to be unreliable in minor (≤10°) asymmetry but half as often recognized in more severe (>10°) asymmetry (Table 9).

Table 9. Patients’ subjective estimation compared to the control visit findings (n=65).

<table>
<thead>
<tr>
<th>Symmetry</th>
<th>≤ 5°</th>
<th>&gt;5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>&lt;6-10°</td>
<td>&gt;15°</td>
</tr>
<tr>
<td>Extension</td>
<td>deficit</td>
<td>hyper</td>
</tr>
<tr>
<td>Carryng Angle</td>
<td>varus</td>
<td>valgus</td>
</tr>
</tbody>
</table>

According to Flynn’s criteria, the outcome was good or excellent in 60/65 (ROM) and 56/65 (CA) of the control visit patients (Table 10). ROM asymmetry exceeding 10° was registered in 5/65 children (four flexion, one extension deficit) attending the clinical examination (Figure 24). The AHL crossed the capitellum in four of these five children’s radiographs at fracture union (one patient’s lateral view radiograph was unusable for radiographic parameter measurement). Elbow flexion deficit exceeding 10° correlated with lower subjective functional outcome (mean score 5.5 [range 3–10], p=0.03; Figure 4). The number of children operated on by a registrar was 4/5 (one by the registrar alone, three by the registrar under supervision; p=1.00).

Table 10. Long-term outcome according to Flynn’s criteria at follow-up visit (n=65).

<table>
<thead>
<tr>
<th>Fracture type (Gartland)</th>
<th>Loss of motion</th>
<th>Loss of carrying angle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>II (10)</td>
<td>III (53)</td>
</tr>
<tr>
<td></td>
<td>flexion (2)</td>
<td>flexion (2)</td>
</tr>
<tr>
<td>Satisfactory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent (0–5°)</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Good (6–10°)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fair (11–15°)</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
CA asymmetry to varus exceeding 10° was measured in 9/65 patients (Table 10). None of these nine patients had a BA more than 10° outside the normal range or radiological evidence of malrotation at fracture union. CA varus asymmetry exceeding 10° correlated with decreased subjective cosmetic (p=0.005) and functional (p=0.004) outcomes. All of these nine children were operated on by registrars (six by registrars alone, three by registrars under supervision).

**Figure 24.** Carrying angle and elbow range of motion in 65 patients at a mean of nine years after pin fixation of a supracondylar humerus fracture.

No asymmetry (> 5°) in supination nor pronation was found. The lengths of arms and forearms were equal. Radiographs of both elbows were taken in 12/65 children (10 varus, two flexion restriction). Three children had a hole at the olecranon fossa. One child’s radiograph showed small calcifications. No signs of avascular necrosis or degenerative changes were found.

Complication rate (iatrogenic nerve injury, re-reduction, deformity corrected by osteotomy, CA or ROM asymmetry >10°) was greater in children operated on by a registrar (55 operations by the registrar alone, 95 with a consultant assisting) (17/150 vs 2/60, p=0.11).
6 DISCUSSION

6.1 POSTPONING OPERATIVE TREATMENT OF SCHF (I)

Emergent pin fixation for displaced SCHF has been justified to stop swelling, which could at least theoretically reduce the number of open reductions and decrease complications such as compartment syndrome, nerve injuries and infections (Mehlman 2001). However, the rate of treatment-related complications has not been reported to increase when delaying operative treatment of displaced SCHF from 8 to 12 hours (Leet 2002, Mehlman 2001, Gupta 2004, Sibinski 2006, Kronner 2013, Larson 2014). Our findings in postponing operative treatment to office hours are concurrent with these earlier studies with no increase of iatrogenic nerve injuries or vascular catastrophes leading to Volkmann’s contracture. The rate of open reductions did not increase significantly by delaying surgery to office hours, which supports previously reported data (Mehlman 2001, Leet 2002, Gupta 2004, Kronner 2013).

The mean duration of operating room time for our patients deceased by 11 minutes after scheduling operative treatment of SCHF to office hours. This was probably due to the fact that more operations were performed by or assisted by an experienced consultant surgeon than before, even though this may not be the only explanation, since there was no significance difference in operating room time between registrars and consultants. However, comparison between these two surgeon groups is impossible, since the children operated on by registrars alone were more likely to have Gartland grade II fractures. A substantial amount of operating room time (16.5 hours) was saved in this study after the new regulation. Furthermore, there was a shift to less expensive operating room time during the daytime (on-call operating room costs are 30% more expensive in our hospital). There was no increase in days in hospital after postponing operative treatment. Thus, treatment of displaced pediatric SCHF became less expensive after November 2004 in our hospital.

Postponing operative treatment of displaced SCHF to office hours has several positive consequences. However, a longer wait in hospital before surgery after admission can cause anxiety for patients and their parents. Therefore, repeated clinical assessment of the neurovascular findings and adequate preoperative pain management is obligatory if operative treatment of displaced fractures is postponed to office hours.
6.2 RADIOGRAPHIC FOLLOW-UP (II)

Postoperative radiographs within 7–10 days and at pin removal are common practice, even though radiographic follow-up has been shown to have little effect on clinical management or long-term outcome (Ponce 2004, Karamitopoulos 2012). Postoperative radiographic controls were routinely taken in our hospital before 2012. During assessment of the long-term outcome of displaced SCHF in children treated in our institution during 2002–2006, we realized that postoperative radiographs had little value in clinical decision making. Thus, after 2012, an instruction was given that postoperative radiographs should not be taken after clinically stable pin fixation with satisfactory alignment (stability tested intraoperatively and fluoroscopic images stored). During the second study period (2012–2014), the number of postoperative radiographs gradually decreased, but even in 2014 approximately one-third of the patients still had unnecessary imaging studies performed (i.e. they had no effect on patient treatment).

Alignment of the distal humerus in the frontal plane can be registered in radiographs by calculating the Baumann angle and clinically by measuring the carrying angle (Dai 1999, Shank 2011, Silva 2010, Smajic 2013, Williamson 1992). Due to the relatively wide degree of normal variation of the Baumann angle in children (almost 20°) and errors in measurement of the Baumann angle (up to 7°), the reliability of radiographic evaluation has been questioned (Silva 2010). Dai evaluated the Baumann angles of injured (SCHF) and non-injured children and found a relation between the Baumann angle and a clinical carrying angle (Dai 1999).

In our study, the correlation of the Baumann angle with the diagnosed deformity was low. Despite the fact that an abnormal Baumann angle was measured in almost one-third of our patients’ elbows after pin fixation, no reoperations were performed and only one corrective osteotomy was performed for gun-stock deformity. CA asymmetry to varus exceeding 10° was measured in 9/65 patients attending the clinical examination. None of these nine patients had a BA more than 10° outside the normal range or radiological evidence of malrotation at fracture union. In addition, the Baumann angle was not measurable in 8% of patients in radiographic controls. Still, the Baumann angle seemed to have predictive value for the subjective long-term outcome: the mean subjective scores for appearance (scale 0–10) were lower in nine patients with BA values exceeding the normal values by 10°.

Thus, in our opinion, the Baumann angle has little predictive value regarding objective outcome, and the quality of reduction in the frontal plane is therefore better evaluated by clinically or radiologically (from intraoperative fluoroscopic images) comparing the CA of the injured and non-injured elbows perioperatively.
The quality of reduction in the sagittal plane can be assessed in radiographs from the AHL or from the LCHA and clinically by recording elbow range of motion (Otsuka 1997, Omid 2008, Herman 2009, Shank 2011, Skaggs and Flynn 2015). No comparison of these two radiological methods has been reported before. In our study, the AHL and its relation to the bony capitellum were almost always assessable (98%) and its correlation with clinical results was far better than that for the LCHA (with the AHL passing the capitellum in 84% of cases vs normal LCHA in 40% of cases). No corrective osteotomies were performed for sagittal plane malunions. ROM asymmetry exceeding 10° was registered in 5/65 of patients attending clinical examination in our long-term outcome study and the AHL crossed the capitellum in 4/5 of these patients, with one patient’s radiograph deemed undiagnostic. The AHL in relation to the capitellum did not affect the subjective cosmetic or functional long-term outcome in our study.

Even though the predictive value was poor regarding the outcome, the intraoperative clinical estimation of complete elbow range of motion can be difficult to attain – partly because of swelling and partly because of the pin fixation – and thus we recommend recording the sagittal alignment of the fracture by the AHL method. In our opinion, reduction can be considered satisfactory if the AHL crosses the bony capitellum at any part, although the AHL has been shown to pass through the anterior or middle thirds of the capitellum in a normal elbow (Herman 2009). Despite the fact that one-third of fractures were fixed with one or no pin crossing both fracture fragments, reduction was compromised in only 10 (4%) cases. Pins that do not penetrate bone in both fracture fragments might still give some stability, especially if partly placed under the periosteum. This is in line with previous literature, since LOR has been reported to occur in 4% of patients with lateral pins only and 2% with crossing pins (Woratanarat 2012, Pennock 2014). Karamitopoulos et al. (2012) concluded that mild changes and pin migration in postoperative radiographs have little effect on clinical management or long-term outcome. Our study supports this finding, since of the 10 children with LOR, no child’s fracture healed in subjective significant malunion, no further treatment was needed and no reoperations were performed. In addition, nine patients’ primary reduction and/or pin fixation was performed insufficiently and should have been recognized earlier in image-intensifier pictures. All the 10 children with LOR were fixed with an inadequately placed medial pin. As previously suggested by Moseley (2012), this could mean that only one adequately placed medial pin would be enough to stabilize a well-reduced fracture in an above-elbow cast.

Nonunion of SCHF is very rare. We did not find a single case in our compensation claim study of 7,000 distal humerus fractures in children. Pin removal was delayed for four patients during the study period 2002–2006 because of a suspected delay in radiological ossification. In retrospect, all fractures were radiologically healed and pin removal could have been performed as scheduled. No nonunion or early
DISCUSSION

Refracture occurred in the later study period, 2012–2014. This supports our current belief that radiographs are of little or no value at pin removal.

The only patient in our radiographic control study who had a corrective osteotomy for gun-stock deformity had six unnecessary elbow radiographs taken. In our opinion, this patient should have been followed up clinically by recording elbow ROM and CA. One set of elbow radiographs would have been enough for planning purposes after the decision about corrective osteotomy had been made.

Our current routine is not to take any radiographs to monitor fracture alignment after satisfactory reduction and stable pin fixation. This policy protects the patients against unnecessary ionizing radiation of 0.01 mSV, which is comparable to one day’s natural background radiation (Radiation and Nuclear Safety Authority in Finland). Furthermore, this saves one outpatient control visit for the patient, one workday for the parent(s), and costs to the community of an outpatient control visit and radiograph.

6.3 THE EFFECT OF THE MAIN SURGEON’S EXPERIENCE ON QUALITY OF TREATMENT

Displaced SCHF is the most common operatively treated fracture type in children. Pin fixation of a displaced SCHF is, however, technically difficult to perform, especially for inexperienced surgeons. Liu et al. (2011) have reported that the rate of non-ideal reduction of SCHF performed by a registrar is higher without a consultant attending, with improved outcome only after the first 15 procedures.

Helsinki University Children’s Hospital is the largest institution treating pediatric fractures in Finland and also the largest teaching hospital for pediatric orthopedics in the country. Therefore, the majority of patients in our study were operated on by a registrar (71% in our long-term outcome study). Registrars are initially assisted by consultants at our institution to ensure that they have adequate technical skills before being allowed to operate alone. Consultant help is always available when needed.

Despite the fact that registrars operated on the majority of the children, our long-term objective outcomes (cosmetic and functional) were clearly better compared to the previously reported result (Guven 2015, Sinikumpu 2016). No difference in quality of reduction and pin fixation (AHL crossing the capitellum, BA, LCHA, malrotation, the number of pins crossing both fracture fragments) between the operations performed by registrars and consultants was proven in our study of radiographic controls. This suggests that the quality of teaching is acceptable in our institution. However, in our long-term outcome study, the risk of complication was higher and the long-term outcome was poorer in patients operated on by registrars compared to those operated on by consultants, although the differences did not
reach statistical significance. Thus, we believe that the quality of treatment can be improved with consultant assistance.

The annual number of pin-fixed SCHFs in our institution is three-fold higher compared to the number reported in the study of Guven et al. (2015) in Istanbul and ten-fold higher compared to the earlier report from the joint study of two other institutions in Finland (Sinikumpu 2016). As our long-term objective outcomes were clearly better compared to previously reported results, this supports the finding in our compensation claim study, in which the number of treatment injuries correlates negatively with the level of surgical experience in the treating institution.

In our opinion, operative treatment of pediatric distal humeral fractures should be performed by an experienced surgeon and operative treatment of pediatric distal humeral fractures could be centralized in the five university hospitals in Finland. Postponing pin fixation of SCHF with intact vascular findings to office hours increases teaching opportunities, which we believe will lead to better quality of treatment of pediatric SCHF in the long-run.

6.4 QUALITY OF TREATMENT OF DISTAL HUMERUS FRACTURES IN FINLAND (III)

The nationwide risk for a compensated treatment complication concerning a pediatric distal humerus fracture was 1%. To our knowledge, there are no previous studies of treatment-related complications concerning upper-limb fractures in children in Finland. However, the risk seems to be close to what has been noted in previous studies concerning pediatric tibial (0.4%) and femoral (2.2%) fractures (Palmu 2009 and 2010). Compensation was granted at the same frequency as that for childhood tibial fractures (70%) but at a higher frequency compared with childhood femoral fractures (53%).

Delayed treatment concerned 29/90 patients with a treatment-related complication in connection with a distal humeral fracture (including nine patients with a missed diagnosis). In comparison, delayed diagnosis was found to be the largest subgroup leading to compensation for pediatric tibial fractures (31%) (Palmu 2009).

Nerve injuries turned out to be the third-largest complication of treatment (18/90 patients). The risk of a compensated nerve-related treatment complication was low, only 0.2%. Most of the nerve injuries were considered iatrogenic because the preoperative neurovascular function had been recorded as normal. However, the recording of neurovascular function was usually performed very superficially, making it impossible to determine whether the nerve injuries were caused by trauma or treatment. We suggest that detailed preoperative neurovascular recording be performed to avoid unclear postoperative situations. We question whether all
iatrogenic nerve complications should be compensated for, when they mostly resolve spontaneously without permanent loss of function (Dormans 1995, Ramachandran 2006). One solution could be to grant compensation only when symptoms last longer than the period of immobilization (usually 3–4 weeks). In our study, the risk of nerve injury did not correlate with the number of patients treated monthly (Figure 22), which suggests that most nerve injuries are not complications of treatment, but fracture-related.

Deformity was the most notable complication (53/90 patients). For lower-limb fractures, deformity has been reported to be a much less common complication of treatment (6% for femoral and 9% for tibial fractures) (Palmu 2009 and 2010). The carrying angles of the patients in this register study are unknown. We are thus not able to estimate the number of corrective osteotomies indicated. Only one-third of patients (25/72) who had a corrective osteotomy filed a compensation claim. Of the 25 patients treated with corrective osteotomy who filed a compensation claim, 15 were initially treated without reduction of the fracture. In only one case, the fracture position worsened during cast immobilization. In the rest of the cases, unsatisfactory primary reductions were accepted. The risk of deformity was three times greater in institutions that treat patients operatively less frequently than every second week, compared with institutions that treat patients weekly (Figure 22).

The independent expert and the PIC medical advisor disagreed with the decisions made by the PIC in 13% (15/118) of the cases. This is a significantly higher rate than that reported by Palmu et al. (2009 and 2010) concerning pediatric tibial and femoral fractures (one disagreement with the PIC decision in 80 cases). Half of the claims concerning delayed treatment received no compensation. The delay in receiving correct treatment was mostly one day and, according to decisions made by the PIC, it did not lead to any harm (patients were later treated with a cast). Our independent reviewers would have given compensation for temporary pain. Some of the patients were left without compensation from the PIC even though a corrective osteotomy was performed because of a deformity. In our opinion, every deformity leading to the need for a corrective osteotomy should be compensated for, excluding deformities caused by growth arrest, which are rare. We suggest that compensation claims concerning distal humeral fractures in children should be evaluated by medical advisors with experience in pediatric orthopedics.

6.5 LONG-TERM OUTCOME OF PIN-FIXED SCHF IN THE CHILDREN’S HOSPITAL, HELSINKI (IV)

There are only a few previous studies concerning long-term subjective outcome for pediatric SCHF. Sinikumpu et al. (2016) have reported the 12-year long-term subjective outcome for 81 patients assessed by the Mayo Elbow Performance Score,
but most of the patients had nondisplaced SCHF that was treated nonoperatively. The mean Mayo score in the 25 patients with Gartland grade III fractures was excellent (93), but no range was reported. In their study of 154 cases of Gartland grade III SCHF with a minimum follow-up of 18 months, Wang et al. (2017) evaluated the outcome of 33 neurovascular injury patients compared to patients with intact neurovascular findings. They used the Pediatric Data Collection Instrument (PODCI) and Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) outcome measures, both indicating excellent function. They found no statistically significant difference in outcome measures between the neurovascular injury patients and those with intact findings. No differences in outcomes were identified based upon age, fracture site, sex, weight, direction of displacement or operative technique in neurovascular injury patients. They speculated that a difference in the PODCI and DASH scores among groups could have been missed.

In our study of 210 operatively treated SCHF patients (Gartland grade II and III and flexion-type) with 80% follow-up (168 patients), 92% of patients were satisfied with their outcome. The rate of Volkmann’s contracture was zero, the risk of deep infection and permanent treatment-related nerve complications was low (<1%). Subjective cosmetic outcome correlated negatively with open reduction in our study, which is most likely due to the scar. The number of patients with unsatisfactory subjective results would probably have been smaller with a better quality of fracture reduction and pin fixation (satisfactory alignment at fracture union in 82% of patients). Quality of reduction at fracture union has not been reported in the previous studies (Guven 2015, Sinikumpu 2016).

Sinikumpu et al. (2016) reported pain in 36% of patients with Gartland grade III fractures, whereas after grade I or II fractures the prevalence of pain did not differ from normal age-matched controls. In our study, fewer patients (14%) reported pain without correlation with fracture grade and reported pain was associated with nerve injury. Guven et al. (2015) reported good or excellent objective functional and cosmetic long-term outcome (mean 22 years of follow-up) using Flynn’s criteria in 33 and 43 of their 49 SCHFs treated with open reduction and cross-pin fixation (clinical follow-up rate 12%). In the study by Sinikumpu et al. (2016) (follow-up rate 76%), good or excellent result were achieved in 22/33 patients with Gartland grade II and III SCHF treated with either percutaneous or open pin fixation after a minimum of 10 years of follow-up. Our results were clearly better, with good or excellent cosmetic and functional outcome in 56 and 60 of the 65 clinically examined patients (follow-up rate 31%) after mean follow-up of nine years.

In Simanovsky’s study (2007), 3/10 children with elbow flexion restriction exceeding 5˚ had not recognized the ROM asymmetry, and mild (up to 7˚) hyperextension of the elbow was registered in seven children. Only restricted elbow flexion was considered to be a functional problem. In our study, only one third of patients with minor elbow ROM deficiencies (less than 10˚ asymmetry) had noticed
the asymmetry, whereas two thirds of patients with more pronounced asymmetry were aware of CA or ROM discrepancy between their elbows. Our results are in accordance with Simanovsky’s finding that decreased elbow flexion is a functional problem. We suggest that, in the future, only good and excellent results according to Flynn’s criteria should be classified as satisfactory, since asymmetry exceeding 10° in elbow ROM and CA was clearly associated with poorer subjective results in our study.

6.6 STRENGTHS AND WEAKNESSES OF THE STUDY

In the study concerning postponing operative treatment of SCHF to office hours, we were not able to find statistically significant differences in complication rates (iatrogenic nerve injuries, infection, deformities), which might be because of a relatively small number of patients (200). The two retrospectively analyzed patient groups differed in the level of experience of the main surgeon. In a greater number of patients we might have been able to show whether the operating room time at night differs from the operating room time during office hours, regardless of the surgeon’s level of experience. In particular, the benefit of consultants attending operations could be questioned, since the benefit of having an assisting surgeon, regardless of his/her operative experience, was not analyzed.

Retrospective data collection from medical records, with incomplete preoperative neurovascular status records, made it impossible to determine whether nerve injuries were injury- or treatment-related.

Quality of reduction and pin fixation in displaced SCHF in two separate study periods was assessed in a retrospective study of follow-up radiographs, so the results should be compared with caution. Although the follow-up rate (87%) can be considered high, we do not know the outcome of the remaining patients, who could not be contacted. In addition, one might question whether patients’ satisfaction regarding the cosmetic and functional outcome could worsen over time (minimum follow-up of one year). Malunion in the coronal plane usually results in cubitus varus, which does not remodel or worsen (Guven 2015). In our experience, patients with subjective unsatisfactory alignment seek treatment soon after the injury, with clinically evident deformity. This is supported by the literature since the corrective osteotomies for cubitus varus after pediatric SCHF are performed in pediatric orthopedic clinics (Raney 2012).

Radiographic measurements had little value in predicting subjective or objective outcome. One reason is probably the relatively large normal variation (almost 20°) and intra- and inter-rater errors (up to 7°) of measuring the BA (Silva 2010). We analyzed the quality of fracture reduction in the frontal plane by comparing the BA
with reported normal values, although we should have compared the BA of injured and uninjured elbows.

The real number of treatment complications is likely to be higher than we reported, since our study was based on compensation claims filed with the PIC. There can be multiple reasons not to file for compensation. Not all doctors properly inform their patients about the compensation system and not all informed patients want to file a claim. Some patients may fear that claims might have a negative impact on their future treatment. Furthermore, it is possible that not all patients filed for compensation during the study period, since the compensation claim must be filed within three years from the date the suspected treatment injury was first noticed (not from the fracture date). A factor that improves the reliability of this study is that there is only one institution evaluating all suspected treatment complications in Finland.

Even though the follow-up rate in our long-term outcome study was high (80%), only 31% participated in a control visit. However, there was no difference with regard to fracture type or quality of primary treatment between those children who participated in either part of the study and those who did not. The factors limiting children’s participation in a control visit were most likely the long follow-up time and the young age at injury, leading to less vivid memories of the fracture, long distances (most of the patients lived outside Helsinki) and a good outcome. The attendance in our study was, however, better than for previous long-term studies of SCHF in children (Simanovsky 2007, Guven 2015, Sinikumpu 2016, Wang 2017). The use of a validated scoring system, such as QuickDASH, could have made it easier to compare our results with other long-term studies, even though they lack questions concerning cosmetic outcome, which in our opinion is important especially in SCHF in children, since the most common complication, cubitus varus, is mainly considered to be a cosmetic problem.
7 CONCLUSIONS

The objectives of this study were: to assess the impact on treatment outcome of postponing operative treatment of SCHF to office hours; to evaluate whether postoperative radiographs are needed after pin fixation of SCHF; to assess the quality of treatment of pediatric distal humerus fractures in Finland; to determine the objective and subjective long-term outcome of operatively treated SCHF in the Children’s Hospital, Helsinki.

Based on the results of this study, the following conclusions can be drawn:

Postponing the operative treatment of SCHF when there is no compromised distal blood circulation to office hours increases consultant attendance in operations. This improves registrar training and decreases operation time without a change in the complication rate or length of hospital stay, decreasing treatment-related expenses.

Reduction of displaced SCHF is acceptable when the AHL crosses the ossification center of the capitellum in the sagittal plane and when the CA is restored to within 10° of the contralateral side. The routine use of postoperative radiographic follow-up does not appear to be justified.

Complications in the treatment of distal humerus fractures are rare in Finland. Most of them could be avoided by the following means: a radiograph should be taken if a fracture is suspected; an injured elbow should be immobilized; the threshold for consultation should be kept low to support correct assessment of fracture alignment; a satisfactory standard of operative treatment should be attained. Neurovascular findings at admission should be recorded properly to avoid confusion about nerve injury origin (fracture- or treatment-related).

The long-term cosmetic and functional outcomes in operatively treated SCHF are satisfactory, with few exceptions, if elbow ROM and CA can be restored to within 10° of the uninjured elbow. Patients’ subjective estimation of minor (<10°) asymmetry in elbow ROM and CA is unreliable. Nerve injuries can cause long-term pain.

Operative treatment of pediatric distal humerus fractures should be performed by or with the assistance of an experienced surgeon. The operative treatment of these fractures should be centralized in university hospitals in Finland.

Based on our study conclusion, we have formulated guidance and an intraoperative checklist for operative treatment of supracondylar humerus fractures in children.
8 PIN FIXATION GUIDANCE FOR PEDIATRIC SCHF

**Primary goal:** to treat/prevent vascular complication

**Secondary goal:** to avoid permanent iatrogenic nerve injury and growth arrest (result of drilling several times through growth plate)

**Tertiary goal:** stable pin fixation of fracture in satisfactory alignment

**At hospital admission:**
- register distal blood circulation (color, temperature and capillary reaction of the hand as well as distal radial pulse)
- register nerve function (motor and sensory function)
- register carrying angle of the uninjured elbow (take a photograph if possible)
- instruct intravenous antibiotics in open fractures
- immobilize the injured elbow in 30° of flexion to prevent pain
- program immediate operation for open fractures and fractures with compromised distal blood circulation

**Reduction (extension-type supracondylar humerus fracture)**
- make sure that the patient has received muscle relaxant
- first do frontal plane reduction with elbow at extension
- hyperextend the elbow and do posterior to anterior reduction of the distal fracture fragment, pushing the distal fragment (turn the patient’s thumb to point in the same direction as the distal fracture fragment dislocation before reduction)
- flex the elbow fully while pushing the distal fracture fragment anteriorly (if not possible, something might be trapped between fracture fragments)
- if closed reduction fails after three attempts, do an open reduction via anterior approach

**Acceptable reduction**
- the anterior humeral line (AHL) should pass the ossification center of the capitellum at the sagittal plane (prefer middle or anterior third)
- communion of medial and lateral columns (especially avoid collapse of medial column)
- evaluating the Baumann angle from intraoperative fluoroscopic images can be challenging (normal 64–81°) – target for symmetrical elbow-carrying angles compared to uninjured side
PIN FIXATION GUIDANCE FOR PEDIATRIC SCHF

- slight ad latus displacement can be accepted – be exact with rotatory and angular reduction

Pin fixation
- crossing pins:
  - use 1.8 mm K-wires
  - be aware that the ulnar nerve can subluxate on the medial epicondyle at elbow flexion (small skin incision and blunt dissection to bone is preferable)
  - pins should run at medial and lateral columns and cross proximal to the fracture line
- lateral pins
  - use 2.0 mm K-wires
  - at least 10 mm separation at the fracture line
  - use oscillate drilling mode
  - make sure that both pins penetrate both fracture fragments
  - pins should puncture the cortex approximately 5 mm at the coronal plane (proximal to fracture line)
- test stability of pins: stable pin does not rotate or is not retractable by hand
- test fixation stability by valgus-varus test, by rotation tests and by pushing the distal fracture fragment posteriorly (by pushing antebrachium posteriorly at 90° elbow flexion)
- bend pins at 90° angle 1 cm from skin, protect skin properly and close skin incisions with resorbable sutures

Intraoperative fluoroscopic images
- the fluoroscopic monitor is best positioned next to patient hand pointing towards the patient’s body when the patient upper limb is fully extended and the shoulder is at 90° abduction
- document the fixation stability with stored fluoroscopic images
  - frontal plane images: both in valgus- and varus-stress tests
  - sagittal plane images: both in inner- and outer-rotation tests
  - sagittal plane images: both in posterior and anterior stress tests
After reduction
- register distal blood circulation (color, temperature and capillary reaction of the hand as well as distal radial pulse)
  • normal perfusion – no action
  • compromised distal blood circulation – wait for 20 minutes
  • if the perfusion does not return to normal – exploration of the brachial artery
- if normal preoperative pulse is lost after operation, the brachial artery can be bound to the fracture line at reduction

Casting
- cast elbow to 90° of flexion if distal blood circulation is normal (make sure that the cast does not press the K-wires)
- if distal blood circulation is compromised, use 30° of elbow flexion with loose binding

Operation document
- register whether reduction was performed by closed or open means
- register whether the AHL crosses the ossification center of the capitellum
- register carrying angles of both elbows (degrees)
- report how many drilling attempts before success (repeating drilling can cause vascular problems and growth arrest)
- register pin fixation stability
- register the total number of intraoperative fluoroscopic images taken

Postoperative controls
- postoperative radiographs are not needed routinely
- schedule pin removal at approximately 3–4 weeks without control radiographs when acceptable reduction and stable fixation
  • open fractures or open reduction -> 4 weeks
- schedule a radiographic control ≤7 days
  • if fracture alignment was not satisfactory
  • if stability of pin fixation is unsure
9 INTRAOPERATIVE CHECKLIST FOR PIN FIXATION OF SCHF IN CHILDREN

Before anesthesia in operating room:

1. Distal blood circulation is normal (capillary reaction and radial pulse). YES / NO
2. Child can perform OK-sign (flexion of index and thumb DIP and IP/AIN and abduction of digits III–V/ulnar nerve). YES / NO
3. Child can perform “thumbs up” (extension of wrist and thumb/radial nerve, flexion of digits II–III/median nerve). YES / NO
4. Preoperative sensation of the hand is normal. YES / NO
5. The carrying angle of the uninjured elbow is registered (sagittal radiograph). YES / NO

Immediately after pin fixation in operating room:

6. AHL crosses the ossification center of capitellum. YES / NO
7. BA is within 10˚ compared to the uninjured elbow. YES / NO
8. At least two pins penetrate both fracture fragments. YES / NO
9. Pins puncture the cortex approximately 5 mm. YES / NO
10. Crossing pins: the pins cross proximal to the fracture line. YES / NO
11. Lateral pins: at least 10 mm separation at fracture line. YES / NO
12. Fixation is stable in internal and external rotation stress tests. YES / NO
13. Fixation is stable in valgus and varus stress tests. YES / NO
14. Fixation is stable in anterior to posterior stress tests. YES / NO
15. All six fluoroscopic images are stored. YES / NO
   a. sagittal image of uninjured elbow
   b. fixation stability in internal and external rotation stress tests (sagittal plane x 2)
   c. fixation stability in valgus and varus stress tests (sagittal plane x 2)
   d. fixation stability in anterior to posterior stress test (sagittal plane x 2)
16. Pins are bent at 90˚ angle approximately 1 cm from skin level and cut 1 cm from the bend. YES / NO
17. Pins do not irritate or stretch the skin at elbow cast position. YES / NO
18. Distal blood circulation is normal (capillary reaction and radial pulse). YES / NO
After casting the elbow:

19. Elbow is immobilized at 90° angle (if normal blood circulation). YES / NO
20. Cast extends from knuckles to upper part of arm. YES / NO
21. Cast does not press the pins. YES / NO
22. Pin tips do not puncture the cast. YES / NO

Fracture reduction was performed by closed/open means.

During the operation _____ fluoroscopic images were taken.

Fracture was fixed with _____ crossing/lateral pins.

Medial pin(s) was drilled successfully at _____ attempt.

Lateral pin(s) was drilled successfully at _____ attempt.
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