FOREARM SHAFT FRACTURES IN CHILDREN

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Abstract

There are previous reports of an increasing incidence of children’s forearm fractures in the last few
decades. Their surgical treatment is evolving. The present study was aimed at determining the
incidence and background of these fractures and their treatment. It was also aimed to analyse the
short- and long-term outcomes.

A comprehensive population-based study (N=168) among 86,000 children in Oulu University
Hospital District over a decade (2000–2009) was performed to analyse the incidence of middle-
third forearm fractures. Further data (N=291) covering 1997–2009 was achieved in order to study
monthly variation and backgrounds of all both-bone forearm fractures in the distal, middle or
proximal thirds. An age- and sex-matched case-control study (N=94) at Vaasa Central Hospital
District in 1995–1999 with approximately 11 years of follow-up was performed to evaluate long-
term morbidity. The relationship between summer weather and outdoor fractures was based on
daily weather readings of all summer days (N=1989) in 1997–2009.

There was a 4.4-fold increase in middle-third shaft fractures in the last decade (2000–2009) and
a 3.1-fold increase in all forearm shaft fractures (proximal, middle and distal) in 1997–2009. The
increase in the middle-shaft fractures was still accelerating towards the end of the study period.
Trampolining was increasing as a reason for the injuries. At the end of the study every third
fracture was caused by a trampoline injury. The fractures caused by other recreational activities
increased absolutely, but they were stable in relation to trampoline injuries. There was a clear
monthly variation in fracture incidence. During the long study time, August was repeatedly the
most usual month for the fractures. School terms and summer holidays did not explain the varying
fracture risk. The incidence of the fractures was 50% higher in dry vs. rainy days in summer.
Temperature and wind speed did not affect fracture risk.

Not only were the number of children’s forearm shaft fractures increasing, but also their
operative treatment in 1997–2009. The increase was mostly connected to elastic stable
intramedullary nailing (ESIN), the incidence of which changed from 10% to 30% during the study
period, compared with other types of treatment. Non-operative treatment showed poor short-term
outcome in the form of worsening alignment and a relatively great need of re-operations.
Operative treatment showed excellent primary results. In the long run, the outcome of non-
operative treatment was excellent.

Keywords: adolescent, bone fractures, child, complications, forearm, incidence,
operative surgical procedures, seasons, treatment outcome, weather
Sinikumpu, Juha-Jaakko, Lasten kynärvarren murtumat.
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Tiivistelmä

Lasten kynärvarren diafyysimurtumat ovat lisääntyneet viimeisten vuosikymmenten aikana. Samalla niiden kirurginen hoito on muuttunut. Tämän tutkimuksen tavoitteena oli selvittää murtumien ilmaantuvuutta ja murtumien taustalla olevia tekijöitä sekä hoidon kehittymistä. Tavoitteena oli myös tutkia lyhytt- ja pitkäaikaisia hoitolukuksia.


Asiasanat: hoidon vaikuttavuus, hoitoluku, ilmaantuvuus, kesä, komplikaatiot, kynärvarsi, lapsi, leikkaushoito, luunmurtumat, nuori, sää
Sammanfattning

Barns underarmsfrakturer har ökat under de senaste årtiondena och deras behandling är under förändring. Syftet med den här forskningen var att undersöka underarmsfrakturer: förekommande, bakgrund och behandling. Meningen var också att bedöma resultat av olika frakturbehandlingar på kort och lång sikt.


Operativa kirurgiska behandlingar ökade i stället för ej-operativa behandlingar åren 1997–2009. Ökningen berodde mest på tilltagande bruk av flexibla märgspikar, vilket ökade från 10 % till 30 % jämfört med andra behandlingsmetoder.


Ämnesord: barn, behanlingsresultat, benbrott, incidens, kirurgisk vård, komplikationer, underarmarna, ungdomar, väderlek
To children
Preface

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Juha-Jaakko Sinikumpu

31st October, 2013

Villa Augusta

Oulu
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Abbreviations and some definitions

Delayed union A fracture that heals more slowly than normal in the bone in question. The forearm shaft should develop callus within the first four-five weeks of fracture.

Diaphysis The shaft of a long bone, resulting from periosteal, membranous ossification of the original endochondral model; a stable structure where periosteal osteoblasts produce new layers of bone during growth increasing its thickness (1).

DRUJ Distal radio-ulnar joint

Epiphysis A cartilaginous structure (chondroepiphysis) at the end of the each long bone that goes thorough chondro-osseous transformation at a time characteristic for each bone (1).

ER Emergency room

ESIN Elastic stable intramedullary nail(ing)

IOM Interoosseus membrane (between the forearm bones)

K-wire Kirschner wire

Metaphysis The part of a long bone between the growth line and the diaphysis, showing active bone turnover by osteoblasts and osteoclasts and being in response to converting newly created mineralized cartilage to true bone tissue (1).

Nonunion A fracture that shows no bone healing in a time typical for the bone in question. In the forearm, union should be seen in at least six months.

PRUJ Proximal radio-ulnar joint constructed by several ligaments, t.ex. annular and radial collateral ligament

Osteoclasis Surgical fracture of a bone in order to achieve reduction

ORIF Open reduction and internal fixation

Osteosynthesis A surgical procedure to stabilize a broken bone with any implant

OT Operation theatre

PCCF Pediatric comprehensive classification of fractures

Physis The growth plate of a bone between the epiphysis (secondary ossification centre) and the diaphysis (primary ossification centre); chondrocytes there being in response to longitudinal and latitudinal bone growth (endochondral ossification) (1).

ROM Range of motion

TFCC Triangular fibrocartilage complex
List of original articles

The thesis is based on the following original publications.


The publications are referred to in the text by their roman numerals. The articles were reprinted in this thesis with the kind permission of the copyright holders. In addition, some unpublished results are presented first in this dissertation. They are indicated by the text “previously unpublished in individual articles”.

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1 Introduction

The forearm is a fascinating anatomical structure that redistributes forces from the hand to the upper part of the extremity and allows the hand to rotate. The forearm is not only an axle but also a non-synovial joint (2). Its skeleton is peculiarly formed by two separate bones, the radius and ulna. Two bones provide good range of rotation motion (ROM), while remaining light and stable (3). Muscles, nerves and vessels are fixed on the turning bone (the radius) far away from the wrist and hand keeping the hand slim and dexterous (4). The functions of the hand and the forearm are complex and none of the best robots have yet been able to imitate them (5). The forearm is necessary for the upper extremity to function perfectly.

Being so complex and important in relation to function of the upper extremity, injuries of the forearm can result in potentially hazardous consequences. There is no doubt that forearm shaft fractures are potentially harmful and challenging to manage (6). They are unique and they differ from fractures of any other long bones (7). They are one of the few paediatric fractures that show a real risk of complications and prolonged morbidity (8). The most challenging forearm fractures are both-bone fractures in the middle-third of the shaft (9).

In children, forearm both-bone shaft fractures cover about 6% of all fractures. Many authors have reported that the incidence of pediatric forearm shaft fractures is increasing (10–12). This is somewhat different to the trend of fractures in the children population generally, which is decreasing or is controversial as regards incidence (13). Diet, milk taking, D-vitamin and physical exercise for example play a role in pediatric fractures. However, non-medical factors of bone breaks are of greater importance than medical factors among children, as compared to the adults (14). Predisposing factors of forearm fractures should be better understood. The increase remains a mystery and further studies are warranted (15).

In addition to above, there have been reports of increasing operative treatment of forearm shaft fractures. Elastic stable intramedullary nailing (ESIN) has become common in the treatment of children’s long bone shaft fractures (16). It was first reported for the treatment of long bones by French and Spanish surgeons at the late 1970s and early 1980s (17–20). The procedure is under active research and new innovations are being developed, for example by using biodegradable implants (21). Plate and screw fixation has become rare and non-operative treatment less popular in cases of children’s forearm shaft fractures (22).

Regardless the increasing interest in operative treatment (in particular mini-invasive surgery) in forearm shaft fractures, there is great disagreement...
concerning the indications for operative treatment (23). Most of the forearm shaft fractures are traditionally treated by non-operative means. No consensus regarding acceptable alignment or reduction has been found in evidence-based studies (24). It is possible that the recent increasing trend of operative treatment is a phenomenon that feeds itself, without any actual scientific argument! Evidence for and against the increasing open surgery and diminishing non-operative treatment is warranted.

In this study, it was decided to take up the challenge and research the incidence and backgrounds of forearm shaft fractures in children and adolescents in detail. It is important to study the epidemiology of the fractures to develop preventive strategies (25). It was also aimed to analyse the risk factors of these fractures and to look for the reasons behind the increasing rate of operative treatment. In this study it was postulated that both short-term and long-term outcomes are important to justify any treatment. The presumption that operative treatment is superior to non-operative treatment deserved to be proved.
2 Review of the literature

2.1 Anatomy of the forearm

The forearm is a complex anatomical structure between the elbow and the wrist that serves an important function of the upper extremity. The forearm consists of two parallel bones, the radius and the ulna. It forms a functional unit that can be considered both as an axis and a nonsynovial joint (26, 27). This “joint” can be best understood in term of two “condyles”, the distal radio-ulnar joint (DRUJ) and the proximal radioulnar joint (PRUJ) (28). The capsule of the elbow joint and the annular ligament stabilize the bones proximally. Distally, the bones are connected by a wrist capsule, radio-ulnar stabilizing ligaments (dorsal and volar) and a fibrocartilage articular disk (triangular fibrocartilage compex, TFCC) (29, 30).

There is an interosseus membrane (IOM) between the shafts of the radius and ulna. It is important in increasing stability of the forearm, in particular allowing axial stability while the forearm is in any rotation (26). It consists of a central band, several accessory bands, the proximal band and a thin membraneous component (26). The central band runs between the bones in an oblique position and it is the thickest part of the membrane (31). Histologically it resembles the anterior crucial ligament and patellar ligament (32). The IOM has a very limited physiologic ability to heal (33).

2.1.1 Development of the forearm skeleton

Histologically, the forearm contains several differentiated cell types, including bone, cartilage, tendon, muscle and nerve. The upper extremities become visible in the human embryo at about the fourth week of gestation. The formation and differentiation of cartilage-forming chondrocytes and bone-forming osteoblasts is the first embryological step of limb development from the pre-skeletal tissue. By about the sixth week the fingers are seen in the embryo. The muscles are identifiable by the seventh week (34). The radius and ulna ossify in the eighth week of gestation, from the primary ossification centres (35).

The forearm bones continue to develop and grow after birth (36). Bone growth occurs by endochondral and membranous (periosteal) development. There are several anatomical segments in the forearm bones (Figure 1). The physis is the...
main structure synthesizing new bone through endochondral ossification (1). The secondary ossification centre at the distal part of the radius, the radial epiphysis becomes visible via chondro-osseal transformation at the age of approximately one year. There may be a separate ossification centre at the tip of the radial styloid process. Proximally, a secondary radial epiphysis appears at 4–7 years of age (35, 37). 75% of the radial growth occurs at the distal physis (38).

The distal secondary ossification centre of the ulna begin to ossify at about four to six years of age (37). Proximally, the ossification centre of the olecranon appears at 9–10 years of age (35).

Bone development is mostly controlled by local factors in response to mechanical stimuli that act on the bone as well as by hormones and nutrition (10). Height and other individual, anthropometric variables are widely accepted to be inherited (39). In addition, the final bone mass is determined mostly by the genes (40).

Fig. 1. The segments of the growing radius and ulna in the distal part of the forearm.
2.1.2 Radius

The radius is lateral and shorter than the ulna. It is laterally bowed by approximately ten degrees along its length and bowing increases during growth (2, 23, 41). This curve is referred to as the radial bow and it is to be maintained by treatment if a fracture occurs (2). Proximally the radius has a medially directed bicipital tuberosity where the biceps tendon (which acts as a supinator of the forearm) is fixed. The bicipital tuberosity is oriented around 180º away from the distal radial styloid. The distal radial styloid and the bicipital tuberosity indicate the rotational configuration of the forearm, representing another aspect to be considered in forearm fracture treatment (2). The radius has another prominent (apex volar) curve proximally, near to the bicipital tuberosity (around 15º) (2).

The proximal head of the radius in the elbow is covered by a cartilage, being in connection with the distal part of the humerus (capitellum) and the proximal part of ulna. The diameter of the radial shaft enlarges in a proximal to distal direction. It is as its thinnest closely distally from the head at the level of the neck of the radius. In cross section, the shaft of the radius is triangular with a sharp side medially (interosseous border). The IOM is attached there. Distally, the radius forms the radiocarpal joint (wrist).

2.1.3 Ulna

The ulna contributes to stability of the forearm (23). It is thicker proximally, possessing a hook-shaped end (olecranon). Towards the distal end it decreases in diameter and finally, it does not reach the wrist joint at all (radiocarpal joint). The ulna is strongly connected to the humerus and it forms an uniaxial hinge joint in the elbow with flexion-extension range of motion (26). The middle third of the ulna is critical with regard to the intra-osseal vascular supply of the ulnar shaft (42).

The ulna is close to being straight (2). There is a slight apex dorsal bow just distally from the olecranon.

2.1.4 Periosteum

The forearm bones are covered by a thick periosteum in all parts except for joint surfaces. The periosteum consists of an outer fibroblast layer and an inner osteogenetic layer (cambium layer). There are blood and lymph vessels and
nerves in the periosteum and it plays a critical role in bone healing. In children, periosteum has greater osteogenic potential than in adults (1), which allows children’s fractures to be treated more conservatively than adults’ fractures (35). In children, the periosteum separates from the bone more easily than in adults (1). The periosteum initiates fracture healing, producing new bone rapidly. It is potent in filling bone defects in fracture lines. Upon injury, the strong periosteum can act as a hinge, which can make alignment worse. On the other hand, an intact periosteum that lies usually on the concave side (1), holds fracture parts in contact with each others and it may assist closed reduction.

2.1.5 Muscle compartments

There are three muscle compartments in the forearm (43). The volar compartment is surrounded by an antebrachial fascia, the radius, the ulna and the IOM. The volar compartment is divided into superficial and deep parts and they contain the flexor and pronator muscles (44). The dorsal compartment is surrounded by the fascia, the radius, the ulna and the IOM. It contains the extensors of the wrist and fingers. The dorsal compartment is also divided into the superficial and deep parts. The mobile wad compartment is located in the dorso-lateral side of the forearm. There are two wrist extensors and a forearm flexor in that compartment. (37, 45) (Figure 2)

The muscles of the forearm can be classified into three groups according to their functions: 1) those attached to the radius, being involved in movements of the forearm, 2) those extending to the metacarpal area and allowing wrist movements, and 3) those extending to the fingers (37).
2.2 Forearm functions

2.2.1 Movements

The forearm is both a mechanical axis and a joint. It functions as a lever that delivers momentum and enables rotational movements of the hand regardless of the flexion-extension position of the elbow. The dexterity of the upper extremity is dependent on the motion of the shoulder, the elbow, forearm, wrist and fingers.

Rotation of an extremity is the movement that occurs in the forearm exclusively (3). It is dependent on the bowed shape of the radius which changes its axial rotation at the proximal end, swinging the distal end around the distal part of the ulna. (41). The proximal head of the radius pivots within the annular ligament (35). (Figure 3) In full pronation the radius migrates proximally (26). The hand moves in unison with the radius (46). The ulna is the stabilizing part of the forearm. The swinging radius needs enough intra-osseal space. If the distance between the two forearm bones is narrowed, rotation may be limited (47).
The rotational axle in the forearm runs through the centre of the proximal radial head in the elbow distally to the centre of fovea of the ulnar head at the wrist (48). Hence the functional axis is oblique to the longitudinal anatomic axes of both the radius and ulna (26). Intact geometry of the forearm bones is important for their function. (4) (Figure 3)

In children, the normal arc of forearm rotation is about 170 degrees (49). Pronation motion is around 80 degrees and supination around 90 degrees in children and adolescents (50). In the whole population, the arc of rotation is on average 180 degrees (3). The range of motion of the left and right sides are very similar but not identical (51). Together with the motion of the shoulder, the rotational arc of the upper limb is up to 270 degrees (52).

Rotation is an important motion for various activities of daily living such as feeding and personal hygiene (4, 53). Traditionally, it has been thought that supination motion is more important than pronation, as it cannot be compensated for by humeral motion (4). However, pronation is essential when grasping objects. It is obligatory in many daily activities such as typing, writing, using a computer, dressing and drinking (54). Most daily living functions will succeed with around 100º of rotation motion, but some authors have found that a larger arc of motion (127º) is needed (55, 56).
Fig. 3. Forearm rotation is dependent on the bowed radius that swings around the near-to-straight ulna.

Muscles depending on rotational movements

There are two pairs of muscles involved in supination and pronation. Bowing of the radius and its “crank-like” shape is of crucial importance as regards the strength created by the muscles (3, 4, 57). Therefore, the muscles are attached at the precise sites of that “crank-like” bone, producing their rotational turning...
forces (4). Firstly, at the upper part of the radius are the supinator muscle and biceps brachii muscle that create supination. Secondly, lower in the radius at the junction zone of the proximal and middle forearm is attached the pronator teres muscle. Still more distally in the radius is attached the pronator quadratus muscle (28). There are also additional muscles involved with pronation and supination movements, like brachioradialis muscle (4, 58). Supination torque is 15% greater than pronation torque. Supination and pronation forces are stronger when the elbow is in flexion, compared with extension position (37). (Figure 3)

2.2.2 Load transmission

Longitudinal load transmission from the hand to the elbow is a complex interaction that involves the radius, the IOM and the ulna. The central band of the IOM functions in sharing load from proximal radius to distal ulna. Due to its oblique structure from the distal part of the ulna to the proximal part of the radius, the membrane transmits compressing forces received by the hand and radius to the ulna for further transmission upwards to the humerus (58, 59). (Figure 4) Normally most (60–95%) of the load from the distal radius (the wrist) is delivered to the ulna and light load reaches the radiocapitellar joint directly (60, 61).

The carrying angle of the upper extremity affects load transmission between the forearm and the elbow. The normal carrying angle is around 6–12 degrees of valgus in children and it increases with increasing age (41, 62). If the carrying angle increases, more load from the distal radius is transmitted directly to the radiocapitellar joint. In the case of cubitus rectus or cubitus varus, direct load transmission between the radius and the humerus decreases (31). (Figure 4)
2.3 Forearm shaft fractures in children

Forearm shaft fractures can be complete fractures as seen in an adult population. Complete fractures can be transverse, oblique, spiral, butterfly and comminuted. Fractures are closed or open.

In addition, children show unique types of fractures. Torus fractures mean that the cortex is compressed producing a typical bump visible in radiographs (63). In the forearm these fractures are often seen in the distal metaphysis. A greenstick fracture, as a peculiarity among children, means that there is a traction fissure in one cortex and just a compression bump at another cortex (64). Plastic deformation is possible as a result of micro-fractures that occur both in tensile and compressive forms, being typical in a paediatric population (65, 66). Plastic angular deformity can become permanent if it is not noticed and corrected. Slow gradual force is needed to achieve complete reduction, which is mandatory for full restoration of rotation (67). Plastic deformation injury typically lacks
periosteal new bone formation, and invisible callus does not mean a deficiency in healing (68).

**2.3.1 Remodelling**

There are special characteristics of an immature forearm in its response to trauma. Remaining bone growth in children reflects great osteogenic potential and remodelling capacity (69). Remodelling continues after the fracture has healed until the physes close (70, 71). This makes it important to determine the stage of growth plate closure when considering an acceptable fracture position (72).

Remodelling at the fracture site occurs by resorption of the bone on the convex side and generation of new bone on the concave side. This is explained by increased pressure (compression) on the concave side that stimulates new bone formation by means of intramembranous apposition (2). Respectively, on the convex side, the bone is under tension which stimulates resorption (70). (Figure 5)

In addition, remodelling can occur at the physis by altering the direction of bone growth in order to become perpendicular to the forces that act through them (35, 73). In the forearm, remodelling capacity is better in the distal part, compared with the middle shaft. The bone in the diaphysis is rigid, compact cortical bone and relatively avascular (70). Shaft fractures take longer to heal and remodel, compared with other parts of the long bones (70). In the forearm shaft, spontaneous correction of malunion is about one degree per year (74). At the radial epiphysis, the correction is around ten degrees in a year (2). Rotational deformity does not remodel (23).
2.3.2 Injury mechanisms

The forearm shaft consist mostly of the cortical bone, which is strong and needs great trauma energy to damage compared with the metaphysis (75). Falls are the most typical type of injury in cases of forearm fractures. Children’s carefree and vigorous play makes them vulnerable to skeletal injury (76). When children fall, they commonly protect themselves by outstretching the upper extremity (23). In this case, the hand is usually pronated during landing and the thenar takes the first blow against the ground. This leads to rapid supination of the pronated forearm. In this injury the radius absorbs the highest load and fractures first, compared with the ulna (75).

Because of the injury mechanism, there is usually both malalignment and rotational malformation in forearm shaft fractures (35). Malrotation of the forearm is probable if fractures of the radius and ulna are at different levels of the forearm. (23). Despite the angulation, rotational deformity is unlikely if the radius and ulna break at the same level of the forearm (2).

It is longitudinal compression force that is responsible for breaking the forearm bones in most cases. Nevertheless, the direction of immediate malangulation is dependent on the type of injury mechanism (35). With the most common injury mechanism mentioned above, the most usual manifestation of the forearm shaft fracture is supination-apex-volar fracture. It means that the distal fracture part is in supination and the apex of the fracture curves anteriorly (i.e.
apex volar) (67) (Figure 6). Less common pronation fractures have a posterior angular apex (apex dorsal) (35). (Figure 7)

Fig. 6. A supination-apex-volar–fracture that is commonly caused by landing against an outstretched limb, the forearm being in pronation.

Fig. 7. A forearm shaft fracture with apex-dorsal and pronation deformity.

Forearm shaft fractures usually involve both the radius and the ulna. A fracture-dislocation should always be suspected if a single-bone fracture occurs (77). As an exception, a direct blow against a forearm bone may lead to an isolated fracture (23). Such a direct injury may result in sole angular deformity without malrotation.
2.4 Diagnosing fractures

Gross visible deformity, point tenderness and decreased supination and pronation movements are the best clinical predictors of children’s forearm shaft fractures (49). Bone crepitus may be felt (23). Younger, nonverbal children are less easy to investigate and they may show only discomfort with motions and limited activity (23).

Radiographs are diagnostic in forearm shaft fractures and the pictures should be taken in two opposite projections (antero-posterior and lateral) in neutral rotation (27) in order to evaluate alignment three-dimensionally. Angular deformity may occur in any direction beyond the area covered the radiographs. Thus, if angular deformity is visible both in antero-posterior and lateral projections, the true deformity is out of the plane of the radiographs (2) and its magnitude is greater than that measured in a single view (78). Angulation is measured as the total degree of deviation of the distal fragment in relation to the proximal fragment (38).

Both the wrist and elbow should be captured in the same film in order to make it possible to evaluate rotational deformity (75). A mismatch of the cortices on both sides of the fractured bone is indicative of rotational deformity (23). Rotation in the fracture line is also evaluated by comparing the bicipital tuberosity and the radial styloid, which normally lie 180° from each other. Disruption of radial bowing is radiographically determined by antero-posterior projection (27). If the bow is straightened, the bone will also present lengthening that may restrict movements (78).

Magnetic resonance imaging and computer tomography can be used to evaluate the forearm skeleton in detail. They are usually not necessary in acute cases. However, they may be of use in complicated cases, for example when planning excision of a synostosis or correction osteotomy. Former internal implants may disturb further imagining.

2.5 Aims of fracture treatment

Treatment of forearm shaft fractures aims to achieve and maintain acceptable reduction until bone union occurs (79). Because of the unique feature of the forearm as a joint, and unlike other diaphyseal fractures, fractures of the radius and the ulna must be approached like other articular fractures (27). It is not only a question of fracture healing but also of function of a broken joint and possible
stiffness after injury (2). Thus, the main purpose of treatments in the long term is to achieve full recovery of the range of motion in the forearm and minimize complications (80, 81). In addition, further intervention using anaesthesia should be avoided by primarily carrying out definitive fracture care (82).

Concerning the desire functional outcome of forearm shaft fractures, there is still no consensus as regards acceptable alignment to be aimed at (22–24, 83, 84). Decision-making as to accept or not to accept the reduction depends on multiple factors (70, 85). However, some authors have concluded that children of nine years of age or older may tolerate no more than 8–10º of angular deformation in middle-third fractures, at most 30º in rotational deformation and not more than 100% of displacement (86, 87). Children under nine years of age may tolerate 10–15º of angular deformation and 45º of malrotation in middle-third shaft fractures (23, 75, 85, 86, 88). Shortening of at most 10mm is thought to be acceptable at any age (2). However, in cases of total bayonet position (>100% translation) there should be angular deformity of no more than 20º and at least two years of growth remaining (88). (Table 1)

In distal-third shaft fractures 20º of angular deformity may be tolerated, if there are at least two years of growth remaining (2). Price suggested accepting 20º for children under five years of age (86). Total displacement with or without shortening seems to be especially well tolerated in metaphyseal forearm fractures (89). As regards proximal shaft fractures, anatomical reduction should be carried out in children of 8 years or older. Younger children may tolerate 10º of angulation, 30º of malrotation and 100% of translation (86).

Table 1. Acceptable deformity in cases of paediatric both-bone forearm middle-third shaft fractures.

<table>
<thead>
<tr>
<th>Deformity</th>
<th>Children &lt;9 years</th>
<th>Children ≥9 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular deformity</td>
<td>&lt; 10–15º</td>
<td>&lt; 8–10º</td>
</tr>
<tr>
<td>Rotational deformity</td>
<td>&lt; 45º</td>
<td>&lt; 30º</td>
</tr>
<tr>
<td>Shortening</td>
<td>&lt; 10 mm</td>
<td>&lt; 10 mm</td>
</tr>
<tr>
<td>Translation</td>
<td>&lt; 100%</td>
<td>&lt; 100%</td>
</tr>
</tbody>
</table>

Information from articles by Price, by Jones and Weiner, and expert opinion published by Mehlman and Wall (2, 86, 87).
2.6 Indications for non-operative and operative treatments

Most of paediatric forearm shaft fractures are traditionally treated by means of closed reduction and cast immobilization (90–92). In general, non-invasive treatment should be attempted primarily under light sedation in the emergency room or under general anaesthesia in the operation theatre (OT) (86). Nevertheless, sophisticated closed reduction and casting techniques may be underemphasized amongst surgeons at this time (2, 67). Non-displaced stable fractures can always be managed by using a long arm casts (82). Primary operative treatment is supported in cases that evidently show a high risk of poor outcome (86). Operative treatment primarily can be reasoned in order to avoid repeated interventions under general anaesthesia and to avoid further corrective surgery (93).

Greenstick fractures are usually treated non-invasively (94). However, there is a risk of re-malalignment and they can be operated upon primarily if the intrinsic muscle forces are in danger of worsening the alignment (82). Fracture site affects the choice of treatment as closed reduction is more difficult if the radial fracture is proximal to the ulnar fracture (95). Fractures in the proximal shaft have a high probability of leading to loss of motion when managed non-invasively (86): There is greater muscle mass in the proximal area compared with the distal area and the muscles may interfere with fracture reduction and its maintenance in a cast (86). In addition, low remodelling potency at the proximal part of the forearm support active operative treatment (82).

Complete shaft fractures of both the radius and the ulna may not be controlled by non-operative means as a result of their inherent instability (6, 96, 97). Oblique fracture lines together with displacement indicate increased instability (82). Unstable both-bone fractures are operated upon under anaesthesia (83, 88, 98, 99).

Open fracture is an indication for internal fixation (88). Acceptable alignment is less commonly achieved in open fractures than in closed fractures because of bony comminution and the soft tissue entrapment (100). In addition, debridement of the wound is warranted. Beyond debridement, open forearm fractures can be fixed by using implants without an elevated risk of infection (2). Recently, primarily non-operative casting of open forearm shaft fractures after adequate debridement has been under debate (94).

Operative treatment is indicated after failure of closed treatment, caused or not caused by soft-tissue interposition (101). A common reason for unsatisfactory
closed reduction is interposition of the pronator quadratus muscle, annular ligament, periosteum or the IOM (84). In addition, all fractures that show >10° malalignment in the cast despite closed reduction should be operated upon under anaesthesia (82).

Fracture with adjacent joint dislocation usually requires internal fixation (86). This means Monteggia and Galeazzi fracture-dislocations. Operative treatment is primarily treatment also for fractures with severe soft tissue injury or compartment syndrome (23). Another absolute indication for operative treatment is a simultaneous fracture of the distal humerus (a floating elbow) (23, 102).

Concomitant muscle or tendon entrapment in the fracture line may be dealt with standard closed reduction. However, the volar sides of the forearm bones is widely covered by the flexors and in a cases of displaced fracture, they are prone to incarceration. A surgical intervention thorough a small incision may be required (2). Most neurological symptoms in patients with both-bone forearm shaft fractures are neurapraxias. They tend to resolve spontaneously in several weeks and just a routine treatment of the fracture is recommended (2).

Children’s age affects a surgeon’s decision to operate (38). A forearm shaft fracture in an adolescent near to skeletal maturity usually justifies osteosynthesis (101, 103).

In general, forearm shaft fractures are considered to be unpredictable by many (85). Their instability is difficult to predict via plain radiographs (82). There are also non-medical factors such as the experience of the surgeon that may influence the choice of operative vs. conservative treatment (85, 86).

2.7 Non-operative treatment

In cases of greenstick fractures it is important to recognize both angular and rotational deformity, which both need to be reduced (23, 67). As the fracture is a common “supination-anterior (volar)-apex” type, the distal fragment will be reduced to pronation, which usually corrects the angular deformity, too (67). Fine adjustment is performed by way of three-point contact in order to achieve anatomical alignment. In cases of “pronation-posterior (dorsal)-apex” type, a supination position of the distal fragment is aimed. Three-point manipulative force is used to correct alignment (67). Some authors advise completion of a greenstick fracture in order to reduce the risk of re-angulation (23, 94). There are opposing reports that advise keeping the periosteum intact in order to increase stability (2).
Complete fractures often show bayonet shortening and they are controlled by gentle, long-lasting (5 to 10 minutes) longitudinal traction over the fracture site (2). This diminishes muscle contraction and facilitates reduction. Traction itself may also result in spontaneous reduction of possible rotational malformation (104). The fragments are reduced in full end-to-end contact without overriding, accepting at most slight <10 mm shortening, if any (23). Due to potential instability, complete fractures require precise casting if treated non-operatively.

Casting is aimed at neutralising deforming muscle forces around the fracture until it has healed (94). In particular, the supinator and pronation muscles of the forearm act as deforming forces (2). Fractures proximal to the pronator tuberosity and all fractures in the proximal third should usually be immobilized in supination position, fractures in the middle third in neutral position and those in the distal third or distally to the pronator tuberosity in pronation (23, 94, 105). The optimal position of forearm immobilization is best seen under fluoroscopy (35).

A good cast fit is required to maintain alignment (106, 107). A long-arm cast is recommended for children (86). It should be wide enough splint or circular cast to cover both the volar and dorsal sides of the forearm. Volar and dorsal splints can be used together. The cast should fit around the forearm applying appropriate corrective pressure against malalignment (94). The cast should also take control of separation of the radius and ulna to prevent collapse of the interosseus space (23). This emphasizes good moulding of the cast. The cast has to be greater in lateral to medial direction than in anterior to posterior direction (2).

Immobilization of the forearm with the elbow in flexion or extension position has been under debate. It has been postulated that a cast over the flexed elbow does not take control over the proximal part of the fracture. Casting with the elbow in full extension may eliminate the supination force by the biceps and the deforming force by gravity (108–110). For practical reasons, a cast over the elbow in flexion is traditionally used (67).

Plaster of Paris is the most universal material available (67). It is easy to roll and it moulds to the desired shape, being relatively comfortable for the patient (67). The problem is that it loses its shape when wet. There are several synthetic casting materials in use (111). Fibreglass is light but it becomes hard and the edges may be sharp enough to irritate the skin (67, 111). A further-developed form of fibreglass exists and it allows slight motion over the fracture (67). This is used together with hard fibreglass splint in many institutions nowadays.

A long-arm cast will stay in place until callus formation after four-five weeks (112, 113). Casting may be continued six to eight weeks after the injury (23, 88).
Greenstick fractures in particular need a long immobilization time as a result of the high risk of re-malalignment (67). Removal of the cast before six weeks of treatment has been associated with a risk of re-fracture (114). Usually, the established time of immobilization is around 4–6 weeks in many institutions (115).

According to Zionts et al, the subjective results of closed treatment are good in older children (from 10 years in boys and 8 years in girls until skeletal maturity) after about a year. Despite residual angulation (8° in the radius and 9° in the ulna), functional outcome was good and loss of forearm supination was 4° (mean) and loss of pronation 7° (22). In contrast, there are reports of unsatisfactory results of non-operatively treated middle-third shaft fractures in 39–64% of patients (38, 99).

2.8 Intramedullary fixation

Elastic stable intramedullary nailing (ESIN), using flexible titanium nails, has recently become the primary method of surgery in forearm shaft fractures in children (23, 90, 116, 117). It has produced results equally good as plate and screw fixation in cases of unstable fractures (118, 119), with several advantages when compared with plate and screw fixation (78, 116, 120–122).

In theory, ESIN is based on three-points stabilization by means of opposite tension of two parallel implants in the same intramedullary canal (6). In the forearm both bones are fixed separately with single nails. Therefore, stability is dependent on the two nails mandatorily orientated with the tips towards each other. In the forearm, the two separate nails in two separate bones together form opposing elastic concavity at the level of the fractures (74). For this reason both bones should be fixed (117), regardless of opposing reports supporting single-bone nailing (88, 123).

ESIN will not fill the medullary canal, in contrast to rigid intramedullary implants (124). The flexibility of ESIN facilitates callus formation by enabling minimal movement in the fracture (125). It is still strong enough to maintain satisfactory alignment (86). However, rotational alignment is not guaranteed (126).

Two nails with a diameter of about 40% of the minimum diameter of the intramedullary canal are used (74). Too large a nail may impinge upon the bone cortices (127). It may also distract the ulnar fracture when inserted in an antegrade direction, because the ulna is usually narrowest distal to the fracture (6). The bone with worse displacement is nailed first (2, 103). Most commonly, the
radius is more displaced and more difficult to nail compared with the superficially located ulna (6). The entry point of the radius is on the anterior or lateral side of the radius just above the distal physis. The ulna is best reached proximally and antegrade introduction is recommended, with the assistance of fluoroscopy (74, 128). Nails are cut under the skin but the radial nail should be left prominent enough to avoid damage to the extensor pollicis longus tendon (103).

There are several advantages to ESIN. The implants are inserted into the bone far from the fracture site in order to avoid further damage and to keep the haematoma intact (9). The procedure is minimally invasive and relatively simple to apply (101). The method can be used in children of different ages since there is great assortment of implant sizes (83). Satisfactory stability can also be achieved with incomplete introduction of the nails to the ends of the bones (129) and partial osteosynthesis may still maintain alignment (90, 124). Hardware removal is relatively free of complications and easier than removal of a plate (6). Early mobilization may be allowed (122) and some advise not using a cast (74, 121, 130). Others recommend casting beyond ESIN because of the relatively great physical activity of children (90, 101, 131, 132).

ESIN becomes more difficult with time, as callus formation increases and the bone marrow becomes obstructed (38, 82, 133). Other disadvantages include the relatively common need of minor but direct exposure to the fracture in order to achieve open reduction. Conversion from closed to open treatment should be considered not more than after ten minutes of manipulation or after 2 to 3 failed attempts to nail the fracture (23, 103). If open reduction is required, fractures in the middle or distal third are reached via dorsal approach (Thompson’s approach) and proximal fractures by a volar (Henry’s approach) or dorsal approach (23). The posterior interosseus nerve should be protected when approaching the proximal radius dorsally (2).

Functional outcome of ESIN is good or excellent (115) despite the possible need of (minimal) opening (84). The rate of all complications is about 30% but they are usually minor (134). Complications are more probable if the surgeon has little experience of the technique (135). Delayed union or neurovascular complications are rare (0.5–2%) (82, 136) and non-union (0.5–1%) is seldom seen, being solely in the ulna (9, 127, 137). Problems are often related to a technical error such like using nails that are too thin or achieving an asymmetrical position of the nails (74). Single-bone fixation may lead to increased re-displacement (138). Other complications include infection, irritation of the skin, osteomyelitis, synostosis, hardware migration, tendon rupture and hardware
irritation of the superficial radial nerve branch caused by the distal tip of the nail (126).

Steel nails (Kirschner wires) have been used as intramedullary implants in forearm shaft fractures with satisfactory results (139–141). They should be pre-bent like titanium nails and introduced via the blunt tip.

2.9 Plate and screw fixation

Open reduction with compression plate and screw fixation is an effective technique to stabilize a broken forearm (84). It offers full stability if performed properly. Even a “hairline reduction” can be achieved under direct view. Good stability allows early mobilization (101). The method has been reported as a feasible choice in adolescents approaching skeletal maturity (101). It is also a useful method in cases of re-fracture as the intramedullary canal may be obstructed (142).

Many implants and optional procedures are available. The treatment resembles the corresponding surgery in adults. Two incisions are recommended for the two bones to avoid synostosis (143). Four screws are recommended on both sides of the fracture line (2, 98). Evolution of internal fixation has occurred and a floating plate with locking screws instead of compression plating has been developed (144). It has been thought that compression at the fracture site is not necessary to achieve bone healing after closed or open reduction (23). However, there are few reports of the advantages and disadvantages of locking-screw fixation in children.

The problems of plate and screw fixation are related to the surgical approach, and cosmesis and infections (122, 145). Soft-tissue disruption of plating may lead to neurovascular injury, delayed union or even non-union (146). An advantageous fracture site haematoma can be destroyed (147). In addition, there is a risk of nerve damage during implant removal because scar tissue can make it difficult to identify the nerves (148). The need of plate removal is controversial (149).

In a recent meta-analysis the results of plate and screw fixation were excellent in 90% of the cases and there were no more complications compared with intramedullary nailing (145). Westacott et al. came to the same conclusion: the literature shows no difference in functional outcome between intramedullary nailing and plate and screw fixation (118).
2.10 External fixation

A forearm fracture can be maintained by means of external fixation (150, 151). It is an uncommon method in paediatric forearm shaft fractures that should be reserved especially for the most complicated cases with severe soft tissue damage or severe fractures with segmental bone defects (101).

A peculiar method has been described in which pins alone, without any bar, were used together with a cast to build up an external fixation system (152).

2.11 Care after non-operative and operative treatment

Clinical follow-up of forearm shaft fracture healing depends on fracture type and treatment. There is no consensus of opinion concerning an optimal schedule. Greenstick fractures or complete fractures should be regularly controlled by the first two weeks after closed reduction and casting because of the high risk of re-displacement at this time (96). Some authors recommend radiographic follow-up for the first three weeks (23). Usually radiographs are taken at the time of cast removal (23). However, repeated radiographs after the first three weeks from the injury may be useless (153). Especially in stable torus fractures and in cases clinical examination is good at the time of cast removal, additional radiography is unnecessary (154). However, patients should be followed until at least one hundred degrees of forearm rotation is achieved (30).

After removal of the cast, avoidance of participation in sports or other recreational activities with a high risk of trauma is recommended for a further 4–6 weeks (23). In addition, a temporary splint may be useful to protect the forearm for several weeks after cast removal (2).

In cases of osteosynthesis there is usually no reason for repeat radiographs. About 4–6 weeks after the operation plain radiographs are obtained to determine the appearance of satisfactory callus. If callus is visible, immobilization and activity restrictions are progressively relaxed (2). Similarly to non-operative treatment, sports should be avoided for several months depending on further consolidation of the fracture line. Thus, bone healing is determined 3–4 months after the injury.

Removal of intramedullary nails after union is complete is usual practice nowadays (6). Lascombes et al. recommended keeping the nails in for 10–12 months (116). Removal of the deep implants such as plates is associated with a 12.5% complication risk and criticism has been directed at the idea of routine
removal (155). The question of hardware removal in children is under debate, as a result of lack of evidence-based guidelines.

2.12 Complications

**Malunion**

Malunion is common in the forearm because reduction can easily fail (156). Malunion may disturb the sensitive geometry of the forearm skeleton, leading to restriction of motion (27, 103). Surgeons have a tendency to accept less than adequate reduction in forearm fractures as a result of the generally good remodelling capacity of fractures in children, but this may occasionally lead to unfavourable results (157). The primary results should be good enough, as late correction is difficult and uncertain (157). Spontaneous remodelling is worse in the midshaft, compared with the distal third of the forearm (92). Rotational deformity does not improve by way of remodelling processes (157).

**Range of motion**

Loss of motion may be related to length discrepancy, residual malangulation, malrotation deformity and narrowing of the interosseus space (157). Loss of rotation may also be caused by soft tissue scarring, which produces tension on the interosseus membrane (142). Diaphyseal fractures are more often associated with loss of range than fractures in the distal part of the forearm (72). Nearly two thirds (60%) of children with a middle-third forearm fracture may show residual loss of motion in the forearm (158). In cadaver studies, angulation of 20° in the radius or ulna resulted in 30% or more loss of pro-supination (159, 160).

**Delayed union and nonunion**

Healing time in children is short, compared with that in adults (161). The terminology of healing disturbances is diverse and there are no objective criteria for fracture-healing disturbances in children (112, 113). The normal time of bone healing depends on the fracture site and the age of the patient (137). Normally, new periosteal bone on the radius or the ulna is present four weeks after a fracture in children (112, 162). Forearm fractures usually show complete callus over the
fracture site in four cortices by two to three months (2, 137, 158). A fracture that does not show consolidation of the fracture line within the first 4–6 months is classified nonunion (9, 137).

Non-union in children is an uncommon complication (163). Segmental injury, deep infection, need of open reduction and skeletal maturity predict a healing problem (157). About 3% and 1% of non-union rates have been reported in association with plate fixation and open forearm shaft fractures, respectively (2). In the forearm, the ulna is more prone to non-union than the radius (9). The middle third is especially vulnerable because injury may compromise intra-osseous circulation and bone healing (42). In practise, union is considered to be satisfactory if three of four cortices show callus in two projections (115).

There are two types of non-union: hypertrophic non-union tends to heal in the long term. In the forearm, this may take up to 13 months (162). Hypotrophic non-union reflects no capacity to heal without intervention (164). Bone grafting and compression osteosynthesis will be needed in hypotrophic non-union (2). Further explanation of nonunion is beyond this review.

Re-fracture

Re-fracture is a well-known complication in the forearm. Refracture occurs more often after forearm fracture than after any other fracture in children (8). Its incidence in the forearm is about 6–10% (74). It can occur even a year after the primarily trauma (157). A typical time of re-fracture of the forearm is 4–6 months after cast removal (2, 165). There is an 8-fold risk of re-fracture in diaphyseal fractures compared with metaphyseal fractures (165).

Compartment syndrome

Pressure elevation in a forearm muscle compartment is an emergency that warrants urgent intervention if it progresses. Pain, swelling and tenseness are found on physical examination. Voluntary use of the limb is decreased and paralysis will occur. Clinical examination of a child will be impossible (166). Arterial blood flow continues late, which keeps peripherical pulses palpable. When intracompartmental pressure exceeds 30 mmHg it begins to occlude blood flow to the muscles and necrosis will occur. Pressure over 30–40 mmHg in children’s muscle compartment warrants instant fasciotomy (167, 168). Compartment syndrome does not disturb healing of a fracture (169). In the
forearm, the risk of compartment syndrome increases with multiple attempts at closed manipulation (30) and prolonged operation time (170).

**Vascular and nerve damage**

Absent distal pulses, lowered skin temperature, increasing bluish and poor skin circulation with delayed venous filling time are findings in cases of vascular injury in the forearm (171). The primarily intervention is to reduce and stabilize the unstable fracture, protecting further soft tissue damage (172). Compared with adults, children show better vascular limb healing (157).

Nerve damage is uncommon but often connected to hardware removal. The median nerve is most usually damaged (156). Direct injury can lead to nerve rupture. Surgical reconstruction of nerve laceration is facilitated by fracture stabilization. Fixation also protects the nerve from further damage (157). Recovery of neuropraxia should be present in three months. Otherwise further nerve investigation is indicated (2).

**Cross-union and overgrowth**

Cross-union between the radius and the ulna is a rare but serious complication of a shaft fracture. It makes rotation impossible. As open reduction is required in the primary procedure, it should be carried out via two separate exposures, in order to avoid cross-union (173). Cross-union may also follow intramedullary nailing (91). Fracture at the same level of the radius and ulna predisposes individuals to cross-union. Cross-union should be excised 6–12 months after injury and soft-tissue interposition should be performed to prevent re-synostosis (2).

Diaphyseal fractures may stimulate longitudinal growth by increasing the blood supply, causing asymmetry (1). Overgrowth of >2 mm is seen in 24% and 27% of fractures in the ulna and the radius, respectively, but this has no clinical significance (174). This is different to the lower limb, where length discrepancy may cause postural problems.

**2.13 Epidemiology of paediatric fractures**

Up to a quarter of all children are injured every year (175–177) and about 10–25% of these injuries are fractures (8). Thus, the annual incidence of paediatric fractures is 13–25 per 1000 (76, 176, 178). An exceptionally high incidence (36
per 1000) was reported by Lyons et al. (179). About 18% suffer a fracture in the first nine years of life (177). As many as a third to a half of children will suffer a fracture up to the age of 16 years (176, 180). Children show nearly twice as high a fracture incidence as do adults (176).

There is controversy as regards the change of paediatric fracture incidence recently. Some authors have reported decreasing numbers (13, 15, 181), but opposite reports also exist (182, 183). Both results may hold true: fracture incidence in children’s populations varies greatly between countries and areas (184).

2.14 Factors affecting paediatric fractures

Factors affecting children’s fracture risk are multiple, and non-medical causes are of greater importance, compared with the adult population (14, 176). Children are physically active and their lifestyle is incautious. Many children have lots of physical recreational activities. Having many good effects on health and growth, heavy physical activity still increases exposure to injuries. Children’s daily physical activity has increased in recent years (185). Availability of leisure facilities has increased in developed countries, which may increase injuries (179).

More than two thirds of fractures occur after low-energy trauma (186). Overall, the most common cause of paediatric fractures is a fall from below bed height (176). Blunt trauma is a reason for about 20% of children’s fractures (176).

Patient-related contributors

Age is an essential factor affecting fractures in children. Generally, the peak of incidence is at 9–12 years of age in girls and 10–14 years of age in boys (176, 183, 186). The age distribution of fracture incidence in forearm shaft fractures in boys is bimodal: the first peak in fracture appearance is at 6–7 years of age and the second at 13–14 years of age. Among girls the incidence is as its highest in 4–6 years of age and it diminishes thereafter (176).

Fractures are more commonly seen among boys than girls. The male-to-female ratio was 1.5 in a Swedish population of <19-years of age in 1993–2007 (183). In Scotland in 2000, 61% of patients were male (176). The different risks of fractures between genders may be due to different risk-taking behaviours of boys and girls (187). In the upper extremity, fractures are twice as frequent on the
left side, compared with the right (188). That may be a result of spontaneous use of the left, non-dominant hand in protecting the body in fall.

There are biological factors that affect the strength of children’s bones. In early adolescence, during the growth spurt, a transient decrease in bone strength occurs (189). Bone strength is directly dependent on nutrition and inefficient nutrition affects mineralisation (190). Children with bone fractures show lower total bone mass than uninjured children (191).

Vitamin D is obligatory for bone growth and development prenatally and in the early childhood (192). Low vitamin D levels are associated with decreased mineral content of the bone (193). Calcium and phosphate are necessary for bone mineralization (10). Milk avoidance is related to an elevated risk of childhood fractures (190). Carbonic acid beverage overuse has been associated with increased fracture risk in children (194). Children that have not been breast-fed are at an increased risk of fractures (191).

The majority of children with a bone fracture are otherwise healthy (186). However, the forearm, in particular, is a fracture site that may best reflect changes in bone health (195). Several genetic, endocrine or systemic illnesses as osteogenesis imperfecta can affect bone strength, increasing the risk of fracture (186, 196). Use of corticosteroids has been associated with bone fractures in children (186). Obese children present an increased risk of fractures (197, 198). Obesity affects the dexterity of a child negatively and trauma energy of injuries are directly related to body mass (199, 200). Obesity is increasing in child populations in developed countries (201).

Regardless of the specific cause, children with a former bone fracture show a 2- to 3-fold increased risk of further fractures (202, 203). Two thirds of all fractures occur among children that have suffered from a fracture before (202).

**External contributors**

A great part of all children’s fractures (37%) occur at home (186, 204). School is another common place for a trauma (about 20% of all fractures) (186). Outdoor injuries are of greater severity compared with indoor injuries. Playground injuries are common and the trampoline has become an important risk factor of children’s injuries during in recent years in developed countries (205).

Many children take part in organized sports, which increases the time used in physical activities and thus increases the risk of injuries. The number of children taking part in organized sports increased by 5% in 1998–2005 (183). Most
fractures in child athletes occur in the upper extremities (69). However, the role of
organized sports in regard to fractures is unclear. Among boys, sports may
increase the risk of upper limb fractures but in girls the risk may be decreased
(206).

A dose-dependent association between time spent in front of the television or
a computer and wrist/forearm fractures in children has been reported (206). The
popularity of modern alternative amusements such as console games is also
thought to explain the increase of paediatric exercise injuries by decreasing
children’s tolerance to physical stress and trauma (207).

Good weather and increased daylight are related to an increase in accidents
(204). Fracture incidence has been postulated to be twice as high on days with
above-average sunshine than on those below-average (208). Climate may also
have an influence on children’s fractures. A weak evidence exists of a positive
correlation between temperature and paediatric fractures (208).

Season have an effect on children’s fractures. Fractures occur most often in
the summer (14, 176, 204, 209–212), and school holidays increase the risk of
fracture in children (213). Children’s injuries tend to occur in the afternoon and in
the early evening (214, 215).

2.15 Paediatric fractures and their treatment in a historical context

There has been a general trend towards invasive operative treatment of children’s
fractures recently (182). A fundamental reason for the increasing popularity of
operative surgery has been good availability of image intensifiers in operation
theatres. This has made it possible to control paediatric fractures mini-invasively
and percutaneously without traditional open reduction and internal fixation (ORIF)
procedures. In addition, requests to decrease in-hospital treatment and allow a
rapid return to physical activities have driven surgeons towards more invasive
treatments recently (67). A real revolution in the treatment of paediatric long-bone
diaphyseal fractures has occurred during the last three decades (16).

Historically, operative fracture treatment has been greatly affected by four
scientific revolutions: advance in anaesthesia and in antisepsis, the discovery of
X-rays and the development of inert implants. Paediatric fracture treatment has
changed towards operative surgery along with fracture treatment generally (216,
217). Compared with the pioneering paediatric fracture treatment advocated by Dr.
Walter Blount, who was in general sceptical regarding surgery (218), operative
treatment nowadays is much more common than before (25).
3 Aims of the study

The purpose of the research was to increase understanding of children’s forearm shaft fractures. The aim was to obtain updated evidence of the issue for all physicians who treat children’s injuries and for operating surgeons. Another purpose was to gather information for decision-makers in order to improve prevention.

Specific aims of this research were to study:

1. the incidence of paediatric both-bone forearm shaft fractures and their surgical treatment and the changes in incidences in the last decade.
2. the backgrounds and seasonal variation of paediatric forearm both-bone diaphyseal fractures.
3. the effect of summer weather on the risk of children’s middle-third forearm shaft fractures.
4. the short-term outcome of paediatric forearm shaft fractures after operative and non-operative treatment.
5. the long-term outcome of paediatric forearm shaft fractures after non-operative treatment.
4 Material and methods

In this study, the data covered 291 consecutive paediatric forearm both-bone shaft fracture cases in Oulu district in 1997–2009. Middle-third shaft fractures were seen in 168 cases in 2000–2009. In addition, there were 47 paediatric forearm both-bone shaft fracture cases in Vaasa central hospital district in 1995–1999 and 47 randomly selected, age- and sex-matched control cases. The data includes particular meteorological information concerning 1989 days. The study population is described in detail below, with Roman numerals referring to the original articles (I–V).

4.1 Study I

Material

Population-based epidemiological research in Northern Finland was performed. All the children under the age of 16 years who were admitted to the paediatric trauma centre of Oulu University Hospital for diaphyseal middle-third both-bone shaft fracture in a forearm during 2000–2009 were included in the study (N=168). Final inclusion of the cases was made according to a review of the primary radiograph findings together with the original findings by a radiologist.

There is no single established classification system of the forearm fractures (219). The diaphysis of the forearm bone can be defined as a bone between the proximal extend of the bicipital tuberosity and the distal end of radial shaft (38). A fixed distance (5 centimetre) counted from the proximal or from the distal growth plate as demarking points of the shaft has also been used (22). In this study the fractures were classified according to pediatric comprehensive classification of long-bone fractures (PCCF) (220). Shaft fractures with associated disruption of the radiocapitellar joint (Monteggia fracture and equivalents) and the distal radioulnar joint (Galeazzi fracture and equivalents) were excluded. Patients who were hospitalized for the operation and those treated on an outpatient basis were included.

There are no other paediatric trauma units in the hospital district. Paediatric diaphyseal forearm fractures are considered severe injuries and it was postulated that they all had been treated in the same unit during the study period. Local patients who had primarily been treated elsewhere were included in the study
according to their follow-up visits. Non-residents were excluded. All the radiographs were re-analysed. The cohort was inclusive.

The age-matched population-at-risk was ascertained via the national database of inhabitants (Official Statistics of Finland). It varied between 84.562 and 86.385.

**Methods**

A comprehensive review of injuries, hospitalisation and the details of treatment and follow-up was carried out via the computerised database. All the radiographs were analysed twice by both a radiologist and a clinician. The operative summaries were reviewed as well as clinical notes during the in-hospital treatment.

In this study, >15° of malalignment, >30° of malrotation and >100% of displacement were determined as the indicators of unacceptable position postoperatively or during conservative treatment. Angular and rotational deformity were based on the original analysis by a radiologist, if available. In the literature, rotational deformity can be roughly evaluated by visual observation of possible mismatch of the cortices on both sides of the fracture line. A difference in diameters on both sides of the fracture line on the plain radiographs is indicative of axial, rotational deformity (Figure 8) (221). In addition, the anatomical landmarks of the proximal forearm (the bicipital tuberosity) and distal forearm (the radial styloid) are compared to determine if possible malrotation exceed 30° or not (Figure 9) (221, 222). Despite the degrees of malformation, all the patients who underwent an unplanned operation due to loss of position were classified as unacceptable. Treatment was classified as non-operative treatment (closed reduction and application of a cast) and operative treatment (closed or open reduction and internal fixation).

The annual incidences per 100 000 age-related persons were determined as well as other descriptive statistics. Independent t-tests were used to test differences between group means, the χ2 statistic was used to investigate whether distributions of categorical variables differed from one another, differences between two proportions were tested by the binomial standardized normal deviate (SND) test and a change in time was tested by the linear trend test. The Poisson distribution-based χ2 test was used to test the difference in the annual incidence densities between the first and the last follow-up year. The amount of annual diaphyseal fracture increase was estimated by exponential regression analysis. Statistical significance was pre-set at a P-value of < 0.05. The data were analysed
by using IBM SPSS Statistical Software, version 19, and StatsDirect Statistical Software, version 2.7.2.

Fig. 8. The cross-section of the radius shaft is pearl-like shaped. Therefore, a mismatch is seen on the plain radiograph if there is axial malrotation in the fracture.
Fig. 9. The relationship between the radial styloid (the lower spot) and the bicipital tuberosity (the upper spot) a) The forearm is supinated fully without any malrotation, b) Compared with the distal forearm in full supination, the proximal part of the fracture has turned 30º towards pronation. There is a mismatch of the cortices around the fracture line. c) Compared with the fully supinated distal forearm, the proximal part of the radius has turned 90º, being in a neutral position. There is a great mismatch of the cortices around the fracture line.

4.2 Study II

Material

The aim was to analyse the backgrounds and seasonal variation of both-bone forearm shaft fractures. A comprehensive study cohort was primarily collected according to ICD-10 codes and their equivalents in ICD-9. All 291 proximal, middle and distal both-bone forearm shaft fractures in children (<16-years) during 1997–2009 were included. In the study time most of the necessary data was recorded in computerized databases. The potential cases were checked to ensure they filled the diagnosis criteria by reviewing the initial radiographs.
In this study, comprehensive AO-classification of long-bone fractures was used (220): metaphysis was determined by a square that covered the physis of both radius and ulna together. This definition excludes the critical metaphyseal area that is more like metaphysis (223, 224).

Inclusion was thought to be comprehensive. The annual population-at-risk in the catchment area was determined by Statistic Finland. It varied between 84,562 and 87,490.

Methods

In the study, fracture incidence rates annually and monthly, recreational backgrounds, injury types, clinical and radiographic findings, operative and non-operative treatment, re-operations and short-term outcome were studied. Short-term outcome was determined according to the conclusion of the recovery by the treating surgeon at the last out-patient visit in the institution. The outcome was classified into three groups (excellent, fair and poor) according to the principles of the recent Children’s Hospital of Philadelphia Forearm Fracture Fixation Outcome Classification (93). The classification was expected to be useful also for non-operated patients. If there was no reference to a remaining complication or symptom in the original journal notings, the short-term outcome was classified as “excellent”. Patients with remaining minor pathological finding such as slight loss of range of motion in the elbow (flexion <140º) or forearm (<30º loss of supination or pronation compared to another side) were “fair”. “Poor” reflected major loss of ROM (elbow flexion <100º or loss of supination or pronation >30º) or other major complications (infection or compartment syndrome).

4.3 Study III

Material

To investigate the relationship between summer weather and paediatric forearm shaft fractures, a population-based data on forearm shaft fractures in the geographical area of Oulu University Hospital, with about 86,000 children (<16 years of age) in 1997–2009 was used. Both inpatient and outpatient children with both-bone forearm shaft fractures (22-D in AO-classification) were included. Fractures that had occurred in and between May and September (153 calendar
days) were included, while all indoor injuries (N=12) and fractures missing outdoor/indoor information (N=7) were systematically excluded. Weather data was collected by the national weather service, Finnish meteorological institute, based on daily readings. The data was considered to be representative of the geographical area of the population-based study as regards weather fronts. Daily readings captured detailed information on the maximum daytime temperature (degrees Centigrade), precipitation (rainfall in millimetres) and daily maximum wind speed (meters per second, measured as an average of 10 minutes’ observation). The total number of observed summer days in 1997–2009 was 1989. On four days, some meteorological data were missing.

The climate in the study area is described as intermediate, combining the characteristics of maritime and continental climates. The weather conditions during the study period, 1997–2009, fit the normal climate conditions of the study area.

Methods

The seasonal variation detected in Study II was considered to be dependent on summer weather. Therefore, pioneering data on children’s fractures and daily weather conditions was collected at summer time. In the analysis the maximum daily temperature was classified into three groups: >25 °C (hot), 15–25 °C (warm) and <15 °C (cool). More than 25 °C is the established definition of hot weather in the country. Rainfall was grouped into wet (>1.0 mm) and dry (no rain or only a little rain <1.0 mm). The latter included both sunny and cloudy days. Wind speed was classified into three groups: 0–3 m/s (calm), 4–7 m/s (moderate wind) and >8 m/s (strong breeze).

In the study area, the warmest month is typically July, with daily maximum temperatures exceeding 20 °C, while in May and September the daily maximum temperature typically remains below 15 °C. The temperature statistics and monthly distribution during this study period, 1997–2009, fit the normal climatic conditions. (Figure 10) The annual amount of precipitation is 500–650 mm. July and August are typically the rainiest months with monthly precipitation around 70 mm. (Figure 11) Wind variability is about the same during the summer months with a slight increase in September (Figure 12).
Fig. 10. Maximum daily temperature in the geographical study area during the summer time from 1997 to 2009, described monthly in quartiles.

Fig. 11. Daily rainfall in the geographical study area during the summer time from 1997 to 2009, described monthly in quartiles.
The direct association between fractures (yes/no) and different weather conditions every day was analysed. For that reason summer days were classified into fracture and non-fracture days. Logistic regression models were constructed to estimate the influence of weather conditions (daily rainfall, maximum temperature and wind speed) on paediatric forearm shaft fractures. The analyses were driven separately for each variable and also in multivariate analysis for all weather conditions simultaneously. Finally, fracture frequencies are given according to different weather variables.

There were both school term days and summer holidays in the study time between May and September. Summer holiday was determined as 1st June - 15th August every year and the risk of a fracture was compared between school term and holidays according to the three meteorological factors using logistic regression analyses.

The monthly association of fracture incidence and summer weather conditions (maximum monthly temperature and rainfall) was analysed during the study time of 1997–2009. Poisson regression analysis was used to assess statistical significance. Statistical analyses were carried out by using IMB SPSS Statistics version 20.0.0. The statistical significance threshold was set at P <0.05.
4.4 Study IV

Material

In order to investigate short-term outcome and complications of middle-third shaft fractures, all paediatric patients (<16 years) who suffered both-bone diaphyseal middle-third forearm fractures during 2000–2009 were included in this registry based study. There were 168 patients and inclusion was similar to that in Study I. The original data was taken from the computerized hospital database.

Methods

Short-term outcomes of non-operatively and operatively treated forearm shaft fractures were compared. Radiographic bone healing was one of the primary outcomes. Generally, sufficient callus is shown in 4 weeks in children’s forearm fractures (112, 162). Fractures with no sign of radiographic bone healing by 4–5 weeks were classified as ‘delayed union’. Furthermore, radiological fracture line consolidation should be achieved at 7–11 weeks (225). Non-union included the cases among which ossifying operations were performed.

Alignment and reduction were other primary outcomes. Residual angular malalignment and residual displacement of the radius and ulna were determined. There is no consensus of opinion as regards acceptable position of paediatric forearm fractures (22, 86, 226, 227). In this study, over 15° of residual angular malalignment in antero-posterior or lateral radiographs and >10 mm residual ‘ad latum’ displacement were defined as poor radiographic outcomes. In addition, all cases that were re-operated as a result of re-malalignment or re-displacement were classified into the unacceptable outcome group. The finding of axial deformation was based on the original analysis of the radiographs, if available. In this study, over 30° of malrotation was defined as severe.

All other complications of the patients according to journal notes were also analysed. The need of later surgery (re-operation or unplanned operation during the conservative follow-up period), re-fracture, nerve complication, soft-tissue complication or unacceptable scar and compartmental pressure elevation were recognized.

In addition to the comprehensive analysis of the recovery by the researchers, the conclusion of the recovery by the authentic treating surgeon was recognized: It was collected as an independent variable if the clinician treating the patient
initially had or had not stated any disturbance in recovery when closing the follow-up. Therefore, a parallel variable “recovery with complication” was created.

The primarily outcome variables were analysed in two groups according to the primarily treatment. The non-operative group (N=97) included the cases with external plaster cast immobilisation with or without closed reduction. The operative group (N=71) included the cases with closed or open reduction and internal fixation by any method. There were two surgical procedures that were used in this cohort: ESIN (N=66) and plate and screw fixation (N=5). Complications were analysed separately in connection with the different operative procedures. Follow-up findings were based on those noted at routine visits to the institution. The median number of both follow-up visits and times of radiographic examination was three (range 1–9). All postoperative and out-of-hospital visits and radiographs were included. No cases were lost to follow-up.

There are several variables that may facilitate the decision-making process concerning operative intervention in cases of paediatric forearm shaft fractures: In order to take account the dissimilar distribution of severe and mild fractures in the operative and non-operative treatment groups, they were analysed separately. The ‘severe’ group (N=124) included the patients with at least 10 mm displacement in the radius/ulna or both. The ‘mild’ group (N=44) included the fractures with less or no displacement. (Table 2)

The data were analysed by using IBM SPSS Statistics version 20 and StatsDirect statistical software version 2.7.2. Differences in proportions between groups were compared by using the binomial standardised normal deviate (SND) test. Fracture-specific risk factors as regards choice of invasive treatment were sought by using univariate logistic regression analysis. Odds ratios (ORs) with their 95% confidence intervals (CIs) were calculated in connection with age (per year of age), gender, severity of primary injury (at least 10 mm displacement in the radius/ulna or both), compound fracture (no/yes) and time of fracture (per year of fracture) in order to identify the factors associated with choice of treatment. A P-value of 0.05 was chosen as a threshold for statistical significance.
Table 2. Description of both-bone forearm shaft fractures and their severity according to type of treatment in the study population (Study IV).

<table>
<thead>
<tr>
<th>Fracture</th>
<th>Non-operatively treated (N=97)</th>
<th>Operatively treated (N=71)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>% (of all)</td>
</tr>
<tr>
<td>Angular malalignment (degrees)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radius</td>
<td>47</td>
<td>48</td>
</tr>
<tr>
<td>Ulna</td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td>Displacement (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radius</td>
<td>50</td>
<td>52</td>
</tr>
<tr>
<td>Ulna</td>
<td>48</td>
<td>49</td>
</tr>
<tr>
<td>All</td>
<td>97</td>
<td>100</td>
</tr>
<tr>
<td>Severity of fracture**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>87</td>
<td>90</td>
</tr>
<tr>
<td>Severe</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>All</td>
<td>97</td>
<td>100</td>
</tr>
</tbody>
</table>

* in greenstick fractures, ** severe=at least 10mm displacement in the radius or/and ulna

4.5 Study V

Material

The fifth aim of the study was to assess the clinical and radiographic long-term outcome of children’s non-operatively treated forearm shaft fractures at least 10-years after the primarily injury. For that purpose, all children (≤16 years of age) with both-bone forearm shaft fractures in 1995–1999 treated in Vaasa Central Hospital District were retrospectively reviewed. There are no other trauma centres in the area. In all, 220 out of 253 patients were still living in the district. One hundred and forty-three of them (65.0%) agreed to take part in the study and they were evaluated at the out-patient clinic. The shaft was defined as the long bone between the proximal and distal metaphyses (comprehensive fracture classification in children: fracture group D-22). Proximal and distal forearm fractures, fracture luxations and pathological fractures were systematically excluded. Non-operative treatment included closed reduction and casting without any internal fixation.

Primarily radiographic films were analysed by a clinician and a radiologist familiar with paediatric radiographs. According to the plain radiographs, 48 of the patients had diaphyseal fracture, 47 of which were treated non-operatively and included in the study population.
For every patient, one age- and sex-matched control case was selected from the Finnish Population Register and an additional request among the normal population was performed to complete the groups in case of a missing pair. An age difference of a half year was allowed between the fracture cases and control cases at the time of the follow-up visit. (Figure 13)

Fig. 13. Design of Study V.
Fifty-five per cent of the patients were boys (N=26). The mean age of the patients at the time of injury was 8.5 years (SD 3.6; range 3 to 16). The mean age was 8.6 years (SD 4.1; range 3 to 15) among boys and 8.2 (SD 3.1; 3 to 16) among girls. Fifty-three per cent of the fractures were on the left side (N=25). Most of the patients and controls were right-handed (94%, N=44 in both groups) but the cases and their controls were not matched by handedness.

Methods

The original clinical notes of the fracture cases were reviewed to recognize the date of injury and treatment, fracture nature (open/closed), type of treatment
(operative/non-operative), duration of follow-up and short-term outcome. The patients and the controls were evaluated by the same investigators in 2009–2012. Outcome was determined at out-patient clinic visit at a mean of 11 years after the trauma (range 9 to 13 years). Controls were investigated in a similar manner as the fracture cases, expect for radiographic examination. Satisfaction, tolerance of physical activity and work, need of analgesics and cold sensitivity were enquired about.

Clinical tests included ROM in the forearm (supination and pronation) and wrist (flexion and extension), ulnar deviation and grip strength. ROMs were estimated by using a universal transparent goniometer. In the examination of pron-supination, the subjects were sitting, adducting arms with the elbows in 90º of flexion. The forearms were in a neutral position, thumbs upwards. Rotation was taken to be the main feature of the study (81). The normal arc of rotation in children is 170 degrees (49). There is a wide variation of normal pronation (50–80º) and supination arcs (80–120º) in the literature (158). In a recent report, supination range of motion was around 90º and pronation 80º in a normal population corresponding to the age of the cases in the study cohort (50). In this research supination <60º and pronation <50º were classified as a poor results. For a comparison, in the Children’s Hospital of Philadelphia Forearm Fracture Fixation Outcome Index <30º loss of ROM was required for the fair outcome group and >30º for the poor group (93). Even a slight difference (5–10º) in motion arc of upper extremity joints can be important for a patient (228).

The contralateral, normal side may not always be a reliable control when determining the decrease in the range of motion after injury (228). However, it is established practice by many to use the uninjured extremity as a control (115, 158, 229). Therefore, wrist motions were compared with those on the contralateral side. Range of motion in the wrist and grip strength were captured and analysed as continuous variables. Strength was measured by using a hydraulic Jamal gauge (Asimow Engineering, Santa Monica, California). The highest of three attempts was recorded.

Radiographs were taken in antero-posterior and lateral projections in order to determine alignment or malalignment, other residual bone deformity, heterotrophic ossification and cross union between the radius and the ulna. Malalignment of the radius in AP projection was determined considering normal diaphyseal radial bowing. Radial bowing (apex lateral) of <5º or >15º was thought to represent malalignment (230). Progression of growth line consolidation was noted to ensure cessation of longitudinal bone growth. Follow-up films were
analysed twice by both a clinician and a radiologist familiar with paediatric musculoskeletal disorders.

It was a population-based study. All of the non-operatively treated forearm shaft fracture cases in the hospital district in the given time period were requested to attend a follow-up visit. Nevertheless, post hoc power analysis was performed in order to ensure that the study population was large enough as regarding to its purpose. The calculation was based on the normal range of rotation motion (mean 170º with standard deviation of 30º) in the forearm. More than 30º of decrease in pronation or supination was considered to be clinically significant. A type I error was set at 0.05 (P-value). The final sample size of 47 achieved 100% power.

Statistically significant differences in long-term outcomes between the fracture and control cases were assessed by using the paired t-test for continuous variables, McNemar’s test for dichotomous variables and the Ranked Sign test for ordinal variables. Statistical analyses were carried out by using IBM SPSS Statistics software (version 20; SPSS, Chigaco, IL). The threshold of statistical significance was set at P <0.05.

4.6 Ethical approval

The Ethics Committee Board of Vaasa Central Hospital evaluated and approved the study plan as regards the case-control study. For the registry-based studies no approval from an Ethics Committee was required.
5 Results

A synthesis of published and unpublished results is reported here without following the order of the original articles. The results are given for all forearm shaft fractures together (proximal, middle and distal third of the shaft) (studies II, III, V). In addition, more detailed results concerning the middle-third shaft fractures are given separately, if available (studies I and IV). Roman numbers refer to the original articles.

5.1 Characteristics of the patients

Regardless of the fracture site there was a clear male predominance. A majority (70%, \( N=203 \)) of the patients (\( N=291 \)) with both-bone forearm shaft fractures (proximal, middle or distal diaphysis) were males and 30% females (\( P<0.001 \)). (II)

Patients with a forearm shaft fracture (proximal, middle or distal) were a mean of 8.7 years old (SD 3.8; range 1–15). There was no difference in the mean age between genders (\( P<0.734 \)). No change in the mean age of the patients with any forearm shaft fracture (proximal, middle or distal) was seen during the study time (previously unpublished result in individual articles).

Most of the children (84.5%, \( N=246 \)) with a diaphyseal forearm fracture were admitted to the trauma centre on the day of injury (II). A few (\( N=17 \), 5.8%) were admitted one day later (II). Most (80.1%) of all forearm shaft fractures occurred on the non-dominant side (V).

Middle-third fractures

Majority (69.9%) of the patients with a middle-third forearm shaft fracture were males (\( P<0.001 \)) (I). Patients were a mean of 8.6 years of age (SD 3.9; range 1–15). A notable elevation in the mean age of the patients with a middle-third shaft fracture was observed in 2000–2009 (from 6.4 years in 2000–2001 to 8.8 years in 2002–2009, \( P=0.019 \)). (Figure 14) This was obvious in both genders but reached statistical significance among boys (\( P=0.016 \)). (I)
Fig. 14. Mean age of the patients with a middle-third diaphyseal forearm fracture in 2000–2009.

### 5.2 Incidence

The incidence of all both-bone forearm shaft fractures (proximal, middle and distal) increased 3.1-fold (95% confidence interval (CI) 1.7 to 5.9, P<0.001) in 13 years, between 1997 and 2009 (P<0.001). The incidence was 14.8/100,000 in 1997 and 45.2/100,000 in 2009. (II) (Figure 15)
Middle-third fractures

There was a 4.4-fold increase (from 8.2/100,000 in 2000 to 35.9/100,000 in 2009) in the incidence of middle-third both-bone shaft fractures during a decade (95% CI 2.0–10.8; P < 0.001). The increase was 11.7% yearly, meaning that the real increase was accelerating (95% CI 10.5–12.9%, P < 0.001). The overall increase was 338%. (Figure 16) (I)
Fig. 16. The yearly incidence of paediatric diaphyseal middle-third forearm fractures (bars) and their surgical treatment (squares) in 2000–2009.

5.3 Seasonal variation

Forearm shaft fractures (proximal, middle and distal) were most frequent in the summer months in 1997–2009. The peak of incidence was in August (17.9% of all fractures). August was the leading month in fracture incidence in six out of all 13 years in the study and in two additional years it shared this position with another month. In five years out of all 13 years in the study the fractures were most common beyond August. The fewest fractures occurred in December (3.1%) (P<0.001). (Figure 17) (II)
5.4 Fracture pattern

Most forearm shaft fractures in 1997–2009 were located at the middle-third of the forearm shaft (N=198, 68%). Every third fracture was located at the distal diaphysis (29%, N=85). Eight proximal shaft fractures were seen (3%).

A significant change in the pattern of forearm both-bone shaft fractures during the study time occurred: middle-third fractures increased from 9.1/100,000 in 1997 to 35.9/100,000 in 2009 (3.9 fold, 95% CI 1.8 to 9.9, P<0.001). The incidence of distal shaft fractures remained stable (9.3/100,000 in 1997 to 5.7/100,000 in 2009; 95% CI 0.5 to 6.3, P=0.39). There were 0–2 proximal shaft fractures per year in the study period (0 in 1997 and 0 in 2009). (Previously unpublished result in the individual articles)

5.5 Recreational activities and injury mechanisms

Trampolining was the most usual (16.8%) single recreational background of all both-bone shaft fractures (proximal, middle or distal) (Table 3) (II). Most of the trampoline related fractures (91.8%, N=45/49) were located at the middle-third of the forearm shaft, compared with the proximal (2.0%) or distal (6.1%) shaft (previously unpublished result in individual articles).
A fall at a playground was the most common (34%) single type of injury as regards all forearm shaft fractures (proximal, middle or distal) in both genders (boys 36% and girls 30%). Such falls increased by 26% (from 29.8% in 1998–2000 to 37.6% in 2007–9) in the study period but the finding did not reach statistical significance (P=0.1). One fifth (19.3%) of all shaft fractures were sports related. They seemed to decrease from 28% in 1998–2000 to 15% in 2007–2009, but the finding did not reach statistical significance (P=0.07). Traffic injuries covered 7% of the injuries. (II)

A conventional fall was a leading reason (68%, N=32) for all forearm shaft fractures in 1995–1999. Just two (4%) of the fractures occurred at a playground which is less than that in the later cohorts. Other mechanisms of injuries included organized sports (15%, N=7) and traffic injuries (13%, N=6). (V)

Table 3. Recreational activities in relation to all both-bone forearm shaft (proximal, middle, distal) fractures.

<table>
<thead>
<tr>
<th>Recreational activity</th>
<th>Males</th>
<th></th>
<th>Females</th>
<th></th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>Trampolining</td>
<td>34</td>
<td>16.7</td>
<td>15</td>
<td>30.6</td>
<td>49</td>
</tr>
<tr>
<td>Falling outdoors</td>
<td>22</td>
<td>10.8</td>
<td>11</td>
<td>12.5</td>
<td>33</td>
</tr>
<tr>
<td>Bicycling</td>
<td>18</td>
<td>8.9</td>
<td>5</td>
<td>5.7</td>
<td>23</td>
</tr>
<tr>
<td>Falling from furniture</td>
<td>18</td>
<td>18.9</td>
<td>5</td>
<td>5.7</td>
<td>23</td>
</tr>
<tr>
<td>Swinging</td>
<td>14</td>
<td>6.9</td>
<td>8</td>
<td>9.1</td>
<td>22</td>
</tr>
<tr>
<td>Falling from a playground device</td>
<td>15</td>
<td>7.4</td>
<td>3</td>
<td>3.4</td>
<td>18</td>
</tr>
<tr>
<td>Skateboarding</td>
<td>8</td>
<td>3.9</td>
<td>6</td>
<td>6.8</td>
<td>14</td>
</tr>
<tr>
<td>Motorized toy / vehicle</td>
<td>8</td>
<td>3.9</td>
<td>2</td>
<td>2.3</td>
<td>10</td>
</tr>
<tr>
<td>Riding a horse</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10.2</td>
<td>9</td>
</tr>
<tr>
<td>Snowboarding</td>
<td>9</td>
<td>4.4</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Ice hockey</td>
<td>6</td>
<td>3.0</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Wrestling or gymnastics</td>
<td>5</td>
<td>2.5</td>
<td>1</td>
<td>1.1</td>
<td>6</td>
</tr>
<tr>
<td>Football</td>
<td>5</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Cross-country skiing</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>Undetermined play</td>
<td>30</td>
<td>14.8</td>
<td>21</td>
<td>23.9</td>
<td>51</td>
</tr>
<tr>
<td>Unknown</td>
<td>11</td>
<td>5.4</td>
<td>1</td>
<td>1.1</td>
<td>12</td>
</tr>
<tr>
<td>All</td>
<td>203</td>
<td>69.8</td>
<td>88</td>
<td>30.2</td>
<td>291</td>
</tr>
</tbody>
</table>
Middle-third shaft fractures

Every fourth (25%) middle-third shaft fracture was caused by a trampoline injury during ten years of follow-up in 2000–2009. Trampolining was the most important single recreational reason for the middle-third forearm shaft fractures. Trampoline-related injuries increased from 0% to 30–41% during the study time compared with other reasons (trend test, \(P=0.004\)) (Table 4 and Figure 18). Other recreational backgrounds increased absolutely but they decreased proportionally (\(P=0.004\)) (Table 4). (I)

Table 4. Trampolining vs. other recreational activities as a cause of middle-third both-bone forearm shaft fractures.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Trampoline</td>
<td>0 (0)</td>
<td>15.2 (5)</td>
<td>23.3 (7)</td>
<td>40.6 (13)</td>
<td>30.4 (17)</td>
<td>25.1 (42)</td>
<td>0.004</td>
</tr>
<tr>
<td>Other</td>
<td>100 (16)</td>
<td>84.8 (28)</td>
<td>76.7 (23)</td>
<td>59.4 (19)</td>
<td>69.6 (39)</td>
<td>74.9 (125)</td>
<td>0.004</td>
</tr>
<tr>
<td>All</td>
<td>100 (16)</td>
<td>100 (33)</td>
<td>100 (30)</td>
<td>100 (32)</td>
<td>100 (56)</td>
<td>100 (167*)</td>
<td></td>
</tr>
</tbody>
</table>

* Total number of cases 167 (one case with missing data)

The statistical significance was analysed by the linear trend test.

Fig. 18. Number of middle-third both-bone forearm shaft fractures caused by trampolining and other activities.
About 10% of the injuries resulting in middle-third forearm shaft fracture were sports-related (Table 5). There seemed to have been a decreasing incidence of fractures in organised sports but the finding did not reach statistical significance ($P=0.26$).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Organized team sport</td>
<td>18.8 (3)</td>
<td>15.2 (5)</td>
<td>3.4 (1)</td>
<td>9.4 (3)</td>
<td>9.3 (5)</td>
<td>10.2 (17)</td>
<td>0.26</td>
</tr>
<tr>
<td>Slalom, cross-country skiing, snowboarding</td>
<td>0 (0)</td>
<td>6.1 (2)</td>
<td>6.9 (2)</td>
<td>3.1 (1)</td>
<td>1.9 (1)</td>
<td>3.6 (6)</td>
<td>0.58</td>
</tr>
<tr>
<td>Bicycling, skating, skateboarding</td>
<td>6.2 (1)</td>
<td>15.2 (5)</td>
<td>20.7 (6)</td>
<td>0 (0)</td>
<td>9.3 (5)</td>
<td>10.2 (17)</td>
<td>0.35</td>
</tr>
<tr>
<td>Other playground activity, swing</td>
<td>6.2 (1)</td>
<td>9.1 (3)</td>
<td>10.3 (3)</td>
<td>9.4 (3)</td>
<td>12.9 (7)</td>
<td>10.2 (17)</td>
<td>0.46</td>
</tr>
<tr>
<td>Trampolining</td>
<td>0 (0)</td>
<td>15.2 (5)</td>
<td>24.1 (7)</td>
<td>40.6 (13)</td>
<td>31.5 (17)</td>
<td>25.1 (42)</td>
<td>0.004</td>
</tr>
<tr>
<td>Indoor playing</td>
<td>12.5 (2)</td>
<td>9.1 (3)</td>
<td>6.9 (2)</td>
<td>9.4 (3)</td>
<td>9.3 (5)</td>
<td>9.0 (15)</td>
<td>0.83</td>
</tr>
<tr>
<td>Motor vehicle play</td>
<td>6.2 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>9.4 (3)</td>
<td>3.7 (2)</td>
<td>3.6 (6)</td>
<td>0.52</td>
</tr>
<tr>
<td>Falling from ladder, roof etc.</td>
<td>25 (4)</td>
<td>6 (2)</td>
<td>6.9 (2)</td>
<td>3.1 (1)</td>
<td>9.3 (5)</td>
<td>8.4 (14)</td>
<td>0.26</td>
</tr>
<tr>
<td>Falling when running</td>
<td>25 (4)</td>
<td>24.2 (8)</td>
<td>20.7 (6)</td>
<td>15.6 (5)</td>
<td>12.9 (7)</td>
<td>18.0 (30)</td>
<td>0.28</td>
</tr>
<tr>
<td>All</td>
<td>100 (16)</td>
<td>100 (33)</td>
<td>100 (29)</td>
<td>100 (32)</td>
<td>100 (54)</td>
<td>100 (164)</td>
<td></td>
</tr>
</tbody>
</table>

* The total number of cases was 164
Statistical significance analysed by the trend test

No relative change was observed in the incidence of tumbling (22%), falling between levels (21%), falling at a playground (38.9%) or traffic accidents (7%). (Table 6) (I)

<table>
<thead>
<tr>
<th>Injury mechanism</th>
<th>2000–1 % (N)</th>
<th>2002–3 % (N)</th>
<th>2004–5 % (N)</th>
<th>2006–7 % (N)</th>
<th>2008–9 % (N)</th>
<th>All % (N)</th>
<th>P-value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall at the same level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional fall</td>
<td>25 (4)</td>
<td>33.3 (11)</td>
<td>20 (6)</td>
<td>18.8 (6)</td>
<td>17.9 (10)</td>
<td>22.2 (37)</td>
<td>0.16</td>
</tr>
<tr>
<td>Fall on ice</td>
<td>0 (0)</td>
<td>6.1 (2)</td>
<td>6.7 (2)</td>
<td>3.1 (1)</td>
<td>1.8 (1)</td>
<td>3.6 (6)</td>
<td>0.58</td>
</tr>
<tr>
<td>Falling down</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall between levels</td>
<td>31.3 (5)</td>
<td>18.2 (6)</td>
<td>13.2 (4)</td>
<td>18.8 (6)</td>
<td>25 (14)</td>
<td>21 (35)</td>
<td>0.84</td>
</tr>
<tr>
<td>Fall at playground</td>
<td>25 (4)</td>
<td>30.3 (10)</td>
<td>33.3 (10)</td>
<td>50 (16)</td>
<td>44.6 (25)</td>
<td>38.9 (65)</td>
<td>0.47</td>
</tr>
<tr>
<td>Traffic injury</td>
<td>12.5 (2)</td>
<td>3 (1)</td>
<td>20 (6)</td>
<td>3.1 (1)</td>
<td>3.6 (2)</td>
<td>7.2 (12)</td>
<td>0.22</td>
</tr>
<tr>
<td>Other injury</td>
<td>6.2 (1)</td>
<td>9.1 (3)</td>
<td>6.7 (2)</td>
<td>6.3 (2)</td>
<td>7.1 (4)</td>
<td>7.2 (12)</td>
<td>0.88</td>
</tr>
<tr>
<td>All</td>
<td>100 (16)</td>
<td>100 (33)</td>
<td>100 (30)</td>
<td>100 (32)</td>
<td>100 (56)</td>
<td>100 (167)</td>
<td></td>
</tr>
</tbody>
</table>

* N=167 (one case missing data)

5.6 Clinical findings at admission

The most common primarily clinical findings connected with all both-bone forearm shaft fractures (proximal, middle, distal) at admission were visible deformity of the limb (N=158, 54.3%), local hypothermia in palpation distally at the extremity (N=66, 22.7%), tenderness with palpation (N=38, 13.1%), swelling (N=37, 12.7%) and a skin defect (N=27, 9.3%). Neurological abnormalities were seen in ten cases (3.4%) and five had more than one neurological abnormality. Sensation deficit in the ulnar nerve was the most usual neurological abnormality (N=7, 2.4%). Compartmental pressure elevation was seen in three cases (1.0%). Twenty-two (7.6%) of the fractures were open. (II)

The rate of open fractures was 8.9% in the cohort of middle-third fractures (N=15) (I).

5.7 Radiographic findings primarily

Most of all (75.9%, 221/291) both-bone forearm shaft fractures showed primary angular deformity at admission in 1997–2009 (II). Nine fractures (3.1%) were multi-segmental (II).

Angular deformity of >15° was seen in around half of all forearm shaft fractures (53%, N=25/47), one fifth (19%, N=9/47) showed 0–15 degrees of angular deformity and a third (28%, N=13/47) had no deformity primarily in the study covering 1995–1999. In that cohort, over 2 mm of displacement was seen in 31.9% (N=15/47) of the patients with a forearm shaft fracture. Two thirds (68.1%,
N=32/47) showed <2 mm of displacement primarily. Two fractures were segmental (4.2%, N=2/47). (V)

**Middle-third shaft**

Most (81.5%, N=137/168) of the middle-third fractures showed angular deformity primarily in radiographs (I). On average 21.4° of malalignment in the radius and 18.2° in the ulna were seen at admission (IV). Mean primary displacement was 4.6 mm and 2.8 mm in the radius the ulna respectively (IV). Shortening was seen in 12.5% of the middle-third fracture cases (N=21) and 3.1% (N=8) were multisegmental (I). A quarter (26%, N=44) of the cases were classified as severe and 74% (N=124) as mild fractures. (IV)

### 5.8 Primary treatment

Most of all forearm shaft fractures (proximal, middle and distal) were treated at the operation theatre (OT) (92.4%, N=269/291). Internal fixation was performed for 40.9% of them (N=119/291). 7.6% (N=22/291) were treated at the emergency room (ER) or at an out-patient clinic visit. (II)

Forty-two per cent of the patients with any forearm shaft fracture were operated upon on the day of admission. 49% were operated upon one day later and 7% of the cases still later. Closed reduction and plaster casting was the most common (56%) single procedure at the OT. (II)

ESIN increased from 10% in 1998–2000 to 30% in 2007–9 as the method of internal fixation in the study of all forearm shaft fractures (P=0.043) (Table 7). At the same time the use of K-wire fixation decreased from 33% in 1998–2000 to 11% in 2007–9 but the finding did not reach the statistical significance (P=0.055). There was no change in the total incidence of internal fixation between the three years of follow-up periods (P=0.364). (II)
Table 7. Type of invasive fixation of all both-bone forearm shaft fractures in 1998–2009 (N=117).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intramedullary nail, all</td>
<td>57.1 (12)</td>
<td>81.8 (18)</td>
<td>66 (19)</td>
<td>82.2 (37)</td>
<td>72 (86)</td>
<td>0.113</td>
</tr>
<tr>
<td>ESIN</td>
<td>10 (2)</td>
<td>39 (9)</td>
<td>41 (12)</td>
<td>30 (14)</td>
<td>31 (37)</td>
<td>0.043</td>
</tr>
<tr>
<td>K-wires intramedullary</td>
<td>48 (10)</td>
<td>41 (9)</td>
<td>25 (7)</td>
<td>50 (23)</td>
<td>42 (49)</td>
<td>0.799</td>
</tr>
<tr>
<td>K-wires percutaneously</td>
<td>33.3 (7)</td>
<td>18.2 (4)</td>
<td>31 (9)</td>
<td>11.1 (5)</td>
<td>23 (25)</td>
<td>0.092</td>
</tr>
<tr>
<td>Plate and screw fixation</td>
<td>9.5 (2)</td>
<td>0 0</td>
<td>3 (1)</td>
<td>6.7 (3)</td>
<td>5 (6)</td>
<td>0.515</td>
</tr>
<tr>
<td>All</td>
<td>100 (21)</td>
<td>100 (22)</td>
<td>100 (29)</td>
<td>100 (45)</td>
<td>100 (117)</td>
<td></td>
</tr>
</tbody>
</table>

Middle-third fractures

Most (159 cases, 94.6%) of all 168 middle-third forearm shaft fractures were treated at the OT under general anaesthesia in 2000–2009 (Table 8) (I). Invasive or mini-invasive operation was performed in 44.7% of the middle-third shaft fractures (I), for 46% of the boys and 33% of the girls due to a middle-third shaft fracture (difference 13%, 95% CI −3.5 to 27.7%, P=0.097) (IV).

There was a significant increase in the incidence of reduction and internal fixation of middle-third shaft fractures during the study time (from 13.3% in 2000–2001 to 52.7% in 2008–2009, P=0.015). The absolute increase was 14.5-fold in this time (I). At the end of the study period (years 2008–2009), no statistically significant difference in the proportions of operative (52.7%) and non-operative treatment (47.3%) was noted (Table 8) (I)

ESIN was used in 66 (93%) cases and a plate and screws in five cases in order to fix the middle-third shaft fractures. Fifty-eight per cent (N=97) of the middle-third fractures were treated by means of closed reduction and external cast fixation. (IV)

Severe middle-third fractures were more commonly operated upon (77%) than mild fractures (30%) (difference 47%, 95% CI 60%, P < 0.001). (I, IV)
Table 8. Operative activity and surgical procedures for the paediatric middle-third diaphyseal forearm fractures.

<table>
<thead>
<tr>
<th>Operative activity</th>
<th>2000–1 % (N)</th>
<th>2002–3 % (N)</th>
<th>2004–5 % (N)</th>
<th>2006–7 % (N)</th>
<th>2008–9 % (N)</th>
<th>All % (N)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place of treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OT</td>
<td>93.8 (15)</td>
<td>93.9 (31)</td>
<td>96.7 (29)</td>
<td>90.6 (29)</td>
<td>96.5 (65)</td>
<td>94.6 (159)</td>
<td>0.74*</td>
</tr>
<tr>
<td>Out-patient clinics</td>
<td>6.3 (1)</td>
<td>6.1 (2)</td>
<td>3.3 (1)</td>
<td>9.4 (3)</td>
<td>3.5 (2)</td>
<td>5.4 (9)</td>
<td></td>
</tr>
<tr>
<td>Treatment (at the OT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operative</td>
<td>13.3 (2)</td>
<td>45.2 (14)</td>
<td>34.5 (10)</td>
<td>55.2 (16)</td>
<td>52.7 (29)</td>
<td>44.7 (71)</td>
<td>0.015*</td>
</tr>
<tr>
<td>Non-operative</td>
<td>86.7 (13)</td>
<td>54.8 (17)</td>
<td>65.5 (19)</td>
<td>44.8 (13)</td>
<td>47.3 (26)</td>
<td>55.3 (88)</td>
<td></td>
</tr>
</tbody>
</table>

* Trend test

5.8.1 Details of closed treatment

Around half (57.4%, N=27) of the non-operatively treated patients with a forearm shaft fracture (proximal, middle or distal) in 1995–1999 were treated primarily at the OT. The mean time taken for closed reduction and casting at the OT was 21 minutes (range from 5 to 90 min.). Most (81.4%, N=22) of the patients were treated in the evening (16:00–24:00 h), three cases in the daytime (08:00–16:00 h) and two cases at night (24:00–8:00 h). Twenty-two patients (84.6%) were treated by a resident and five (19.2%) by a specialist. (V)

The mean duration of immobilization following non-operative treatment of all forearm shaft fractures was 24.3 days in 1995–1999 (range 14 to 36 days) (V). The mean time of cast immobilization was 34.7 days (SD 13.4) among all shaft fractures in 1997–2009 (II).

There were on average 2.3 follow-up visits per injury (range 0 to 6) in 1995–1999. The rate of immediate complications as regards closed treatment was 36.2% (N=17) in 1995–1999. (V)

5.9 Effect of summer weather conditions

There were 134 summer days when one fracture occurred and 7 days when two fractures occurred. The final both-bone fracture count in the study period was 148. Outdoor fractures occurred commonly on dry, warm and moderate windy days (Figure 19). The incidence was 50% higher on dry days compared with rainy days (P=0.038). The number of fractures was proportional to the number of wet vs. dry days in the analysis because the majority (71%) of days during the study period were dry.
There was no difference in fracture risk between school term and holiday times according to temperature, precipitation or wind (P<0.05 for all).

Fig. 19. Proportional frequencies of fractures according to the three analysed weather variables (rainfall, wind, temperature).

Even when wind and temperature were adjusted in multivariate analysis, a 1.5-fold increased risk of fracture on dry days was observed (P=0.048). Numerically, most fractures (N=116, 78%) occurred on dry days (P=0.039). Just a quarter of the fractures took place on a wet day (Figures 19 and 20). (III)

A clear minority of the fractures occurred on a windy day (5.4%). Wind speed had no statistically significant effect on fractures either alone or after adjusted for daily maximum temperature and rainfall. (III)

A slight majority (51.4%) of the fractures occurred on comfortable average summer days (warm; 15–25 °C). 39.2% of the fractures took place during cool weather and 9.5% on hot days. When the number of days with a different temperature were taken into account, temperature no longer increased or decreased the risk of fracture (P=0.345). (III)
Fig. 20. Distribution of fractures between the dry and the rainy days according to maximum wind speed and temperature.

The monthly fracture incidence in the entire summer time in 1997–2009 was determined according to the average maximum temperature and rainfall. No monthly dependence between the mean maximum temperature and fracture incidence was noted (P=0.399). Neither was any relationship seen between the mean monthly rainfall and fracture incidence (P=0.98). As demonstrated in Figure 21, the summer weather conditions (maximum temperature and rainfall) were stable during the study time but the number of fractures increased towards the end of the period. (unpublished result in individual articles.)
5.10 Short-term clinical outcome

By the last routine out-patient visit at the trauma unit and after taking the possible complications under control, the majority (77%) of all patients with forearm shaft fractures in 1997–2009 (N=223/291) showed finally excellent clinical outcome.
The proportion of excellent results increased from 81.1% in 1998–2001 to 95.2% in 2007–2009 (P=0.016). 7.5% (N=19) showed fair and 4.3% (N=11) poor outcome. (II)

The proportion of patients presenting good short-term outcome without any immediate complication was 63.8% (N=30/47) among the non-operatively treated patients in 1995–1999. 10.6% (N=5) of the patients required later re-intervention. (V)

Middle-third fractures

A majority, 64.2% (N=108/168), of the cases with a middle-third shaft fracture in 2000–2009 recovered without any short-term complications, as observed in routine out-patient visits and according to the treating surgeon. In contrast, 60 patients (35.7%) suffered from some complications, 14 of them showing more than one short-term complications. According to the conclusions by treating surgeons, fractures were more common disturbed by complications after non-operative treatment (58%) than ESIN (25.3%) (P<0.001). Plating and non-operative treatment did not differ in overall complications (P=0.347). (IV)

There were 111 complications in total in the study population in 2000–2009. These complications were determined by the researchers according to clinical and radiographical findings (Table 9, Figure 22). The number of patients with a complication was 61 (42 and 19 in non-operative and operative treatment groups, respectively). Most (N=80) complications occurred after non-operative treatment and 31 occurred after operative treatment. Reoperations were included to complications. (IV)

Table 9. Short-term complications, including re-operations, of middle-third forearm shaft fractures in 2000–2009 after non-operative (N=97) and operative (N=71) treatment.

<table>
<thead>
<tr>
<th>Complication</th>
<th>Non-operatively treated patients</th>
<th>Operatively treated patients</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N (%)</td>
<td>N (%)</td>
<td></td>
</tr>
<tr>
<td>Delayed union</td>
<td>5 (5.2)</td>
<td>6 (8.5)</td>
<td>11</td>
</tr>
<tr>
<td>Non-union</td>
<td>0 0</td>
<td>2 (2.8)</td>
<td>2</td>
</tr>
<tr>
<td>Re-displacement</td>
<td>29 (29.9)</td>
<td>1 (1.4)</td>
<td>30</td>
</tr>
<tr>
<td>Re-fracture</td>
<td>6 (6.2)</td>
<td>6 (8.5)</td>
<td>12</td>
</tr>
<tr>
<td>Nerve damage</td>
<td>4 (4.1)</td>
<td>5 (7.0)</td>
<td>9</td>
</tr>
<tr>
<td>Abnormal scar</td>
<td>0 0</td>
<td>1 (1.4)</td>
<td>1</td>
</tr>
<tr>
<td>Reoperation</td>
<td>36 (37.1)</td>
<td>10 (14.1)</td>
<td>46</td>
</tr>
</tbody>
</table>
5.11 Need of later operation

Every fourth (26.4%, 77/291) of the patients with a forearm shaft fracture in 1997–2009 was operated later, after primarily treatment. Elective removals of the implants were not counted. 41% of the patients that were treated non-operatively (N=71/172) required later operation. Need of later operation was extremely high (82%, N=18/22) among the patients who were primarily treated at the ER. Five per cent of all operated patients needed re-operation (N=6/119). (II)

Middle-third shaft fractures

A fourth (27%, N=46/168) of middle-third fracture patients underwent re-operation for some reason. (Figure 21) Elective removals of the implants were not included. (IV)
5.12 Re-operations according to primary treatment

Middle-third shaft fractures

Among the middle-third forearm shaft fractures in 2000–2009, unplanned re-operations were more common following non-operative treatment (37.1%, N=36) compared with operative treatment (14.1%, N=10) (difference 23.0%, 95% CI 9.8–35.2%, P<0.001). (Table 10) The finding was statistically significant in both the severe fracture group (P=0.018) and the mild fracture group (P=0.011). (IV)

Fracture reduction under general anaesthesia was the most common re-operation (N=30/46, 65.2% of all re-operations). The surgical procedures to perform re-reduction included closed re-reduction and internal fixation (46.7%, 14/30), closed re-reduction and application of a cast (30.0%, 9/30) and open reduction and internal fixation by any method (23.3%, 7/30). (Figure 23) (IV)

There were fewer complications in the ESIN group (24%, N=16/66) than in the non-operative treatment group (58%, N=56/97, P < 0.001) and the plate and screw group (40%, N=2/5, P=0.347). The findings were parallel and statistically significant in both the mild and severe fracture groups. (IV)

Table 10. Re-operations in cases of paediatric middle-third forearm shaft fracture according to operative and non-operative treatment primarily.

<table>
<thead>
<tr>
<th>Reoperation</th>
<th>Non-operative (N=97)</th>
<th>Operative (N=71)</th>
<th>All (N=168)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-reduction</td>
<td>29.9 (29)</td>
<td>1.4 (1)</td>
<td>17.9 (30)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fixation of re-fracture</td>
<td>6.2 (6)</td>
<td>8.5 (6)</td>
<td>7.1 (12)</td>
<td>0.563</td>
</tr>
<tr>
<td>Ossifying the non-union</td>
<td>0.0</td>
<td>1.2 (2)</td>
<td>2.2</td>
<td>0.089</td>
</tr>
<tr>
<td>Skin reconstruction</td>
<td>0.0</td>
<td>1.4 (1)</td>
<td>1.1</td>
<td>0.211</td>
</tr>
<tr>
<td>Neurorrhaphy</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>0.333</td>
</tr>
<tr>
<td>All</td>
<td>37.1 (36)</td>
<td>14.1 (10)</td>
<td>27 (46)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
5.12.1 Re-displacement rate

Middle-third shaft fractures

One-fifth of the middle-third shaft fracture patients (21.7%, N=21/97) in the non-invasive treatment group showed at least 15° of residual malalignment of the radius or ulna in radiographic follow-up. The total incidence of re-operation due to re-displacement was even more, 29.9% (N=29/97), among the non-operatively treated patients. Primarily, 86.2% of them (N=25) were classified as ‘mild’ fractures. (I, IV)

Re-reduction was carried out in one case (1.4%) in the invasive treatment group (I, IV). In this case, only the radius was primarily stabilised by ESIN. The ulna was later stabilised with a plate and screw as a result of re-malalignment. There was no residual malalignment of ≥15° in the invasive fixation group. (IV)
Re-displacement of a both-bone middle-third diaphyseal forearm fracture was seen more often in girls (33.3%, 17/51) than in boys (11.1%, 13/117; difference 22.2%, 95% CI 9.0–36.9%, \( P < 0.001 \)). (IV)

5.12.2 Bone healing

Middle-third fractures

Most middle-third fractures (93.5%) showed callus as a radiographic sign of healing by four weeks. Delayed union was seen in 6.5% (\( N=11/168 \)) of the fractures. Eight of them (73%) were mild fractures and three (27%) were severe fractures. There were no statistically significant differences in delayed union between the non-operative (\( N=5 \)) and operative groups (\( N=6 \)) despite fracture severity (\( P=0.368 \)). No difference in the incidence of delayed union between the genders was noted (8/117 (6.8%) for boys and 3/51 (5.9%) for girls, \( P=0.999 \)). (IV)

There were two (1.2%) patients with ulnar non-union in the cohort (\( N=168 \)). One of the cases had been in a high-energy traffic accident. The fracture was open. Another patient had neurofibromatosis as a chronic disease. Both of these fractures were ‘severe’ and were primarily operated upon. They requested later operation for fusion. (Table 10) (IV)

5.12.3 Re-fractures

Middle-third shaft fractures

The total incidence of re-fractures among middle-third fracture cases (\( N=168 \)) was 7.1% (\( N=12 \)). Re-fracture was seen in 6.2% (6/97) and 8.5% (6/71) of the patients who underwent non-operative and operative treatment, respectively (\( P=0.563 \)). There was no difference in the incidence of re-fractures between boys (7.7%, 9/117) and girls (5.9%, 3/51; difference 1.8%, 95% CI −8.8 to 9.4%, \( P=0.999 \)). Neither was there a difference in the incidence of re-fractures in the ‘mild’ (7.3%) vs. ‘severe’ (6.8%) group (\( P=0.999 \)). (Table 10) (IV)
5.12.4 Nerve complications

Middle-third shaft fractures

There was a 5.4% (N=9/168) incidence of nerve co-morbidity in the cohort. The ulnar nerve was most often affected (N=4). The incidence of a nerve disturbance was 4.1% (N=4/97) among non-operatively treated and 7.0% (N=5/71) among operatively treated cases (P=0.333, Table 2). Three (4.5%) cases with ESIN and two (40%) cases with a plate and screws had abnormal nerve findings (difference $-35.5\%, 95\%$ CI $-72.9\%$ to $-6.3\%, P=0.019$).

One patient (1.0%, N=1/97) who was primarily treated non-operatively suffered total median nerve lesion and needed surgical treatment later. Other nerve complications showed spontaneous healing in follow-up. (Table 10) (IV)

5.12.5 Special complications

Middle-third shaft fractures

One operated patient (1.4%) was left with an unacceptable scar and re-operation was needed. There were no skin problems among the patients who underwent non-operative stabilisation with a cast (P=0.211). (Table 10).

No infections or inflammatory responses were noted in the cohort. There were no compartmental syndrome nor unexpected soft-tissue complications in the cohort of 168 middle-third fracture patients. (IV)

5.12.6 Risk factors of operative treatment of middle-third fractures

Middle-third shaft fractures

Older age, male gender, $\geq10$ mm dislocation in the radius or ulna, open fracture and later year of injury in the study period increased the risk of operative treatment of middle-third shaft fractures. (IV)
5.13 Long-term outcome

5.13.1 ROM and grip strength

Diaphyseal forearm fractures (proximal, middle and distal) did not result in loss of range of prosupination in the long term. There was no statistical difference in prosupination between the fracture cases and their controls (P=0.125) (V).

When the range of motion in the wrist was compared between injured and uninjured extremities in the same cases, no difference in flexion (P=0.569) or extension (P=1.0) was seen. (V)

On the other hand, the range of flexion was 14.9% higher (P<0.001) and extension was 24.3% higher (P<0.001) among the patients vs. the controls. (Table 11) The findings were similar in the uninjured forearms (cases vs. controls, P<0.001). This held true both in fracture and control cases. Fracture cases had greater range of motion (52.7") in the wrist from neutral position to maximal ulnar deviation than controls (42.9", P<0.001) (V).

Grip strength was equally high in both the fracture cases and the controls (P=0.876). It was similar on injured and uninjured sides (P=0.154). (Table 11) (V)
Table 11. Range of motion and grip strength of non-operatively treated both-bone forearm shaft fracture cases after 11 years of follow-up and their randomly selected matched controls.

<table>
<thead>
<tr>
<th>Clinical findings</th>
<th>Fractures</th>
<th>Controls</th>
<th>Diff.</th>
<th>95% CI</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>N (% of all)</td>
<td>Mean (SD)</td>
<td>N (% of all)</td>
<td></td>
</tr>
<tr>
<td><strong>Injured forearm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diminished rotation*</td>
<td>0 (0%)</td>
<td>4 (8.9%)</td>
<td>-8.9</td>
<td>-20.7–0.6</td>
<td>0.125</td>
</tr>
<tr>
<td>Flexion of wrist</td>
<td>85.0 (5.1)</td>
<td>74.0 (7.8)</td>
<td>11.8</td>
<td>8.8–13.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Extension of wrist</td>
<td>83.0 (10.5)</td>
<td>66.8 (9.3)</td>
<td>16.2</td>
<td>12.1–20.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ulnar deviation</td>
<td>52.7 (10.0)</td>
<td>42.9 (9.7)</td>
<td>9.8</td>
<td>6.7–13.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Grip strength**</td>
<td>44.4 (15.9)</td>
<td>44.1 (13.4)</td>
<td>0.3</td>
<td>-3.3–3.8</td>
<td>0.876</td>
</tr>
<tr>
<td><strong>Uninjured forearm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion of wrist</td>
<td>85.2 (5.3)</td>
<td>73.6 (8.3)</td>
<td>11.6</td>
<td>9.1–14.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Extension of wrist</td>
<td>83.0 (10.6)</td>
<td>67.8 (8.0)</td>
<td>15.2</td>
<td>11.2–19.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Grip strength**</td>
<td>44.3 (14.3)</td>
<td>41.3 (13.1)</td>
<td>2.2</td>
<td>-0.8–5.2</td>
<td>0.154</td>
</tr>
</tbody>
</table>

Continuous variables analysed via means and standard deviations (SDs). Difference in means between age- and gender-matched fracture-free control pairs with 95% confidence intervals (95% CIs) and P-values in paired t-tests.

* Number of cases with poor rotation (<60° degrees of supination and/or <50° of pronation) with correlated marginal proportions. Difference in marginal proportions between age- and gender-matched fracture-non-fracture pairs with 95% confidence interval (95% CI) and P-value. McNemar test.

** Measured in kilograms.

5.13.2 Other clinical long-term findings

A crackling sound or sensation during forearm rotation was found in eight cases (18.6%, N=8/43) but in just one control case (2.3%, P=0.039). Diminished tolerance of physical exercise was noted in 21.3% of the patients (N=10/47), against three controls (6.4%). The finding did not reach statistical significance (P=0.092). Other abnormal clinical findings were rare and there were as no difference between the fracture cases and the controls. (V)

5.13.3 Radiographic long-term outcome

Four patients of 47 (8.5%) showed residual local deformity of the radius or ulna in radiographs 11 years after the trauma. No disturbance in radial bowing was
noted as a sign of residual angular malformation. There was no radio-ulnar synostosis or heterotrophic ossification visible in follow-up films. (V)
6 Discussion

The human forearm is necessary to use and control the upper extremity to perfection, in its sophisticated and versatile way. There is no doubt that the human upper extremity is one of the most wonderful tools in the world. It is important in various activities of daily living (53).

Children fall and bump frequently and it is important that their bones do not break in normal life (231). Nevertheless, paediatric fractures are common. Normally, they result in rapid union. However, middle-third forearm shaft fractures in particular are at risk of delayed union or non-union (137). These fractures are challenging to treat and they may be difficult for even the most experienced paediatric orthopaedic surgeons (101).

Furthermore, limb fractures during childhood cause pain and loss of mobility and independence as well as dramatic declines in physical and psychosocial well-being (191, 232). Fractures in children also bring about social burdens for the whole families and fractures may lead to diminished earnings (233, 234).

6.1 Increase of fractures was accelerating

In the first study (I) epidemiology of forearm shaft fractures was analysed. There has been worrying signals of increasing incidences of children’s forearm fractures (10, 12, 182, 235, 236). The overall fracture rate in children has been reported to be increasing or controversial, despite aggressive preventive campaigns (237, 238). The epidemiology of children’s fractures has remained mysterious and further investigations have been warranted in the literature (15). Population-based studies of fractures in Finnish children have been scarce (10).

The study was focused first to middle-third shaft fractures because fractures in that segment are most likely to show delayed union or non-union (137). A 4.4-fold increase in the incidence during one decade (2000–2009) was found. This is parallel but higher number than that in a previous report that was based on the hospital registers in Finland (182). Furthermore, the mysterious increase was still accelerating, making the need for future preventive interventions still more important.

Interestingly, the mean age of the patients rose from 6.4 years in 2000–1 to 8.8 years in 2008–9 (P=0.019). This held true for middle-third fractures, which are usually thought to be caused by high-energy injuries. The rising age of the patients may reflect new recreational activities among older children and
adolescents. For example, trampolining may be an attractive activity for older children. For comparison, the mean age of patients with a forearm shaft fracture was 7.8 years in 2000 in Edinburg (176) and 8.5 years in Helsinki, 2005 (13). However, there is no follow-up data available from Edinburg or Helsinki to analyse the possible change in the mean age of the patients.

The finding of great increase in incidence is clear and generalizable due to comprehensive data. All both-bone forearm shaft fractures were treated at the paediatric trauma unit. It is probable that none or just a few patients were treated at other hospitals. This does not affect the conclusions. In the analysis, non-residents were excluded and the annual number of age-matched population-at-risk was used to obtain incidences.

Not only middle-third but all both-bone forearm shaft fractures were studied. The data was expanded to cover 1997–1999. The data was still reachable from computer-based records. Again, there was a clear increase in incidence (310%) during 1997–2009 (II). The fracture pattern changed in the study period. There was an increase in middle-third shaft fractures, compared with distal and proximal shaft fractures (P<0.001). The finding is of great importance because they are just middle-third fractures that show high risk of complications, compared to distal fractures. The finding deserves to be investigated in further researches.

In general, the great increase in both-bone forearm shaft fractures is alarming and exceptional. The finding was called a mega-trend because of its enormity. This mega-trend affects public health, increasing morbidity of children populations and loading pediatric trauma units.

6.2 Trampolining was the main reason for the fractures

There are several medical factors that are associated with children’s fractures. In addition, several factors that affect bone health, such as diet, vitamin D status and BMI have been associated to children’s fractures (239). Of all children with a bone fracture in Helsinki during a 12 months of period, about 5% showed a reason for further investigations as regard with impaired bone health (238, 240). Nevertheless, this study focused mainly on the non-medical backgrounds of forearm shaft fractures because of they are of greater importance in child versus adult population (14).

Trampoline jumping increased as a reason for the fractures, compared with other reasons (P=0.004). Trampolining explained as much as every third (30.4%) of the middle-third shaft fractures by the end of the study period (2008–2009) (I).
Trampolining was the most important risk factor of both middle-third and all shaft fractures (II). It is possible that the increase in trampoline-related injuries has been caused by the increasing number of the devices. It is thought that there are lots of backyard trampolines in the study district (205). It was found to be impossible to determine the number of imported trampolines during the study time according to statistics from Finnish Customs. However, according to unofficial numbers from a retailer the highest selling years of new trampolines in the country were during the study time, in 2000–2005 (205). Thereafter, the number of new trampolines per year has been postulated not to have increased any more (205). Controversially, trampoline-related fractures continued to increase towards the end of the study time (2000–2009). This may be proof that the number of trampolines in use was still accumulating as a result of their long fit-for-use time.

Most trampoline-related fractures were located at the middle-third segment. It is in line with previous understanding that trampolining is a high-risk activity with potential to lead to orthopaedic injuries (241). In addition, trampolining causes still more light accidents and as much as 86% of all trampoline-related injuries are not presented at emergency rooms (242).

Despite the proportional decrease of other injuries in relation to the trampoline injuries, they also increased in absolute numbers. Therefore, it is clear that children’s forearm shaft fractures are multifactorial. Bicycling was associated with 7.9% of the fractures in this study. It is previously known that bicycle accidents are common reason for pediatric forearm fractures (243). In addition, skateboarding (4.8%), riding a horse (3.1%), snowboarding (3.1%) and several sports activities were causing a number of shaft fractures in this study population. Motored vehicles caused 3.4% of the fractures. Despite the general postulation by lay public that riding a moped has become more popular among female adolescents, in particular, the fractures caused by a motored vehicle did not increase in the study (P=0.52). Another supposition is that riding a kick-scooter has recently become more popular among younger children. These new recreational activities have to be analysed in detail in future studies.

6.3 Most fractures occurred on “nice” summer days

There was clear seasonal variation in the forearm shaft fractures. During the long study time 1997–2009 fractures were most common in August and most uncommon in December (P<0.001) (II). It is postulated that the rate of bone
growth increases in the summer, and the physis undergoes rapid turnover and may therefore be more prone to injury at this time (237). It is possible that remarkably light summers in the study area (close to “the midnight sun”) may affect children’s bones and weaken them towards autumn. According to this hypothesis, not only forearm shaft fractures but all bone breaks should be most common in the late summer time. The seasonal variation should be further researched in the future.

In this study it was thought that non-medical reasons, such as summer weather conditions may be of importance regarding the seasonal variation. Understanding that forearm shaft fractures are caused by high-energy injuries that usually occur outside, it was hypothesized that dry and warm weather would increase the risk of forearm shaft fractures. A clear relationship between dry weather and fractures was found, according to the hypothesis (III). The incidence of forearm shaft fractures was 1.5-fold greater on dry versus wet summer days ($P=0.048$). Fifty per cent of increase in fracture occurrence between rainy and dry days is a big number. It is in line with the results of a pioneering study of the relationship of summer weather and children’s fractures (208). Generally, nice weather is thought to encourage an increase in outdoor activities and warmer months of the year have been shown to be associated with an increase in fractures (14, 176).

This study on weather and children’s forearm shaft fractures was unique being the first one that combined comprehensive population-based fracture data and daily weather readings in a population of children. The weather conditions of every single summer days of 1997–2009 were captured instead of monthly measures. Meteorological data was almost complete, with just three days missing some weather information.

The study must be interpreted within the context of the study design: It have to be recognized that the low number of daily fractures (range 0–2) is a weakness and any increase of relative fracture risk with changing weather conditions could not be evaluated. However, the data was still sufficient to allow determination of accumulation of fractures according to different weather conditions. Further studies with greater numbers of cases per observed days are warranted.

It is also the case that there may have been variations in the nature and/or timing of weather conditions at the fringe areas of the study district that have not been captured in the database. Summer weather is unstable and it can vary in a short distance. For example, summer rain can be a shower that lasts just a moment and is strictly limited to a small geographic area with exact borders between rainy
and dry areas. If one would trace such local meteorological information, the weather radar recordings during the whole study period should be reviewed. Concluding this to be an impossible task it was considered that the method used here was acceptable. The observation station in this study was indicative of weather fronts in the entire area. Weather fronts that glide over the area are relatively stable in their nature. Weather data was collected by Finnish Meteorological Institute according the standards of World Meteorological Organization.

Understanding the limits of the study, it is still clear that the positive correlation between dry weather and increased fracture risk is generalizable. The study opens new avenues to investigate the multifactorial backgrounds of paediatric fractures.

6.4 Operative treatment was increasing – with good short-term results

There was a clear change in treatment of children’s both-bone forearm shaft fractures in one decade, 2000–2009. Non-operative treatment decreased from 87% in 2000–2001 to 55% in 2008–2009. At the same time operative treatment increased from 13% to 45% (P=0.015). The increase in operation activity was mostly due to the increasing incidence of elastic stable intramedullary nailing (ESIN): it increased from 10% in 1998–2000 to 30% in 2007–2009 (P=0.043). (II)

The reason for the increased amount of operations is not unambiguous (22). Traditionally, non-operative treatment has been thought of as sufficient for the vast majority of pediatric forearm shaft fractures (6). The older case-control study cohort (1995–1999) proofs that non-operative treatment has been the dominating method in paediatric forearm shaft fractures. There is no high quality evidence to inform surgeons when to operate and which is the method of choice of surgical stabilisation of a forearm shaft fracture (244). Outcome studies showing superior results of operative methods over those of non-operative methods are scarce (22). It seems to be a sign of frustration as Dr. Ploegmakers and Dr. Verheyen conclude that “The decision as to whether to accept, reduce or operate traumatic paediatric forearm fractures is rarely based on objective empirical criteria. In daily practice, experience and gut feeling are the essential parameters on which physicians rely.” (85)

In order to obtain evidence for the recent trend of increasing operative treatment, the clinical and radiological results of non-operative and operative
treatment of forearm shaft fractures were analysed. A clear finding was that the fractures treated non-operatively showed a high incidence of problems (58%) in the short term. Operatively treated fractures showed a lower complication rate: 24% and 40% of ESIN and plating groups, respectively, had some complications. Consequently, because of a higher risk of problems after non-operative treatment than after operative treatment, the recent trend of increasing incidence of operations may be justified.

In this study all re-operations of both-bone forearm shaft fractures were analysed in detail. Re-fracture, non-union, disturbing scar or nerve damage were equally usual after non-operative and operative treatments. However, there was a statistically significant difference in the need of re-reduction: every third of non-operatively treated and just 1.4% of operatively treated cases required re-reduction (P<0.001). According to these findings, internal fixation will be preferred over non-operative treatment, if the decision is based solely on the short-term complications.

It must be emphasized that the perspective of the analysis was short and only immediate outcome during routine visits at out-patient clinics was considered. The data was based on original information, recorded by the treating surgeons. No structured schema was followed by surgeons at out-clinic follow-up visits. In the study, no comparison could have been performed between the non-operatively treated patients at Oulu University Hospital and Vaasa Central Hospital, because of the cohorts were different as regards with treatment. The casting time in connection with non-operative treatment has been surprisingly short at Vaasa Central Hospital in 1995–1999. However, most fractures showed good short-term recovery there too.

After all, it must also be recognized that 42% of non-operatively treated patients recovered well, without any complication. In this group of patients, non-operative treatment has been the best choice. Thus, an essential question is, how this group of patients could be recognized from the patients that will recover with complications.

As regards operation procedures, many authors prefer ESIN as a primarily method in internal fixation of children’s both-bone forearm shaft fractures (22). In this study, complications were rare after ESIN. Of all operative methods, ESIN is the preferred method of treatment among the authors of the study, too.
6.5 Long-term outcome of non-operative treatment was surprisingly good

Not only short-term but also long-term outcome of both-bone forearm shaft fractures was studied. It was understood that non-operative treatment has been a dominating method of treatment until recent years. Therefore, it was hypothesized that the long-term results of non-operative treatment must be poor: these poor results would have justified the decreasing incidence of non-operative treatment recently.

However, according to the results of the case-control study over 11 years of follow-up, long-term results of non-operative treatment were good or excellent (V). There was no decreased pro-supination compared with healthy controls, which was determined as the most important outcome variable in the study. Similarly, the motion of the wrist in the injured extremity was as good as that in the uninjured side.

Late-stage results of both-bone forearm shaft fractures were otherwise also good. Subjective symptoms were rare, except for decreased tolerance of physical activity (21.3%). However, more than 6% of the randomly selected controls suffered from the same symptom and there was no difference between the groups (P=0.092). Grip strength was equally high among the cases and controls. Crepitus was felt by palpation in every fifth patient under forearm rotation. It was rare finding in the control population (2.3%, P=0.039). Nevertheless, the clinical significance of this non-specific long-term finding is unclear.

The radiological outcomes in the patient-group were also good. Everyone of the patients had achieved normal alignment of the radius and they presented normal radial bowing. No angular malformation was left after 11 years of follow-up. Initially, over half of the patients had shown >15º angular deformity. Some (8.7%) of the patients had a degree local residual deformity in the forearm and the same portion (8.7%) showed signs of degeneration in the radio-carpal joint. This latter finding is interesting. Could it be in relation to crepitus and decreased tolerance of physical activity? In further studies, it would be important to determine if the fractured cases will develop higher numbers of symptomatic osteoarthrosis in radio-carpal joints, compared with healthy control cases.

Beyond the study plan, an analysis of wrist motion between the fracture cases and the controls was performed. An unexpected finding was that mobility of the wrist was better in the fracture cases compared with randomly selected control cases. This is a controversial finding and it is possible that hypermobility in these
cases is rather a cause than a consequence of the fracture. Bilateral finding supports this conclusion. In addition, there are some reports of positive correlation between hypermobility and fractures (245).

Higher mobility among the cases in the fracture group compared with those in the control group is a reliable finding. However, the fact that there were three years between the follow-up visits of the patients and controls should not be ignored. The healthy controls were investigated later, being approximately three years older than the fracture cases. The finding of excellent ROM after severe both-bone forearm shaft fracture warrants new studies with the following hypothesis: “Hypermobility of the joints in healthy children predisposes them to new bone brakes”.

There were some missing cases who were not reached in the study. Probably they would have shown even better long-term outcome than the participating cases. In addition, thanks to the public health care system in the country, the non-participants would have been found to the study according to journal records if they had complained of any problems. The records of all patients in whom both-bone forearm shaft fractures were diagnosed were reviewed.

Because of the satisfactory high participation rate (65.0%) and systematic evaluation of the patients by the same, educated personnel, the good results of non-operatively treated patients in the long-term are clear. The subjective symptoms and abnormal clinical findings of the patients were rare in the long run. This is an encouraging finding that supports the traditional non-operative treatment. It seems to be a good question that shall every effort to operate children’s forearm shaft fractures be unnecessary, because of long-term results are good anyway, after non-operative treatment.

Finally, the most interesting finding in the outcome studies was that short-term and long-term outcomes of non-operative treatment in children’s forearm shaft fractures were opposite. Shortly after the injury there was a significant number of re-interventions (41%) after non-operative treatment. Every third case (29.9%) of the non-operatively treated middle-third shaft fractures was treated again due to worsening reduction. Non-operative treatment caused increased short-term morbidity in the children population compared with operative treatment. In turn, the results of non-operatively treated fractures were excellent in the long term. No one patient showed malangulation 11 years after the trauma. The clinical findings were good and the fracture cases were comparable to their healthy controls.
It must be underlined that according to this study, there are two controversial factors that affect clinical decision-making when one has to choose between non-operative and operative procedures. Surgeons need to consider the advantages and disadvantages of both these treatment methods. Non-operative treatment is easy to perform assuming that the physician and his/her auxiliaries are familiarized with closed reduction and casting technique. In contrast, operative treatment of children’s both-bone diaphyseal fractures can be challenging. There is a learning curve and the beginners show poorer results than seniors (135). Non-operative treatment is cheap and just a little instrumentation is required, whereas a wide assortment of implants and instruments is needed in operative treatment. Non-operative treatment may lead to repeated anaesthesia and intervention due to the high risk of short-term complications. Operative treatment is safe regards the need of repeated anaesthesia and intervention. However, after successful non-operative treatment, there is no need for later intervention at all. In contrast, ESIN is usually removed later in a new operation. This removal of the implant is an elective procedure with relatively low risk of complications.

Long-term outcome of non-operative treatment is good both in radiological and clinical terms. The long-term results of ESIN in the treatment of both-bone forearm shaft fractures are promising (246). However, there is still no very long-term experience, as related to the human lifespan.

In order to avoid immediate problems, to avoid any conflict with parents and to ensure good primary outcome, paediatric orthopaedic surgeons may prefer internal fixation initially. In turn, non-operative treatment can offer excellent long-term results too. This discrepancy of results in the short term and long term engenders “a grey area” for decision-making and it allows paediatric orthopaedic surgeons to justify their own choice — non-operative or operative.

6.6 Future prospects

Children’s forearm shaft fractures have been increasing exponentially. This increase is not completely understood. One third of the rise in the last decade has been due to trampolining but the rest remains mostly unknown. It should be interesting to see further studies set up to analyse the predictive factors of fractures in detail. Again, there are new recreational activities nowadays that are in high fashion among young people, such as riding a kick-scooter and skateboarding. These new activities and their associated fracture risks should be evaluated.
Seasonal variation in forearm shaft fractures is not fully understood. Perhaps the increased incidence of the fractures in August is in relation to a school trip, cycleriding (and falling off), playing with friends or the beginning of a new period of organized sports activities. Furthermore, not only non-medical but also possible medical causes of the increased fracture risk of children in late summer should be evaluated.

A large epidemiological study of children’s fractures in general and prevailing weather conditions is warranted. To achieve as accurate meteorological information as possible, the use of radar maps should be considered. It would also be an interesting idea to ask all patients with any fracture about prevailing weather conditions at the time of injury. Furthermore, it would be important to study if paediatric indoor fractures are associated with weather conditions.

Of great interest in the future will be detailed comparison of different methods of treatment. Could it be ethically acceptable to compare non-operative and operative treatment of all children with a forearm shaft fracture – both mild and severe? That kind of extensive study would show the real differences of the non-operative and operative treatments. A prospective and randomized trial would offer the best evidence for or against any treatment. It would make it possible to generate evidence based guidelines.

In addition, there is a need of evidence for implant removal. There are few reports as regards keeping or removing flexible intramedullary nails in children. Furthermore, biodegradable nails are on trial and a preliminary report has been published (21). The on-going clinical prospective study needs to be continued to determine the advantages and disadvantages of biodegradable materials in diaphyseal forearm fracture treatment among children.

In the future, it will be of great importance to continue monitoring yearly incidence of forearm shaft fractures. It was found that the increase of forearm shaft fractures was accelerating up to the end of the study period (2000–2009). This is different to the signals of decreasing incidences of all paediatric fractures recently (238). This makes it still more important to study the extend to which the incidence of paediatric forearm shaft fractures will rise in the future.
7 Conclusions

A comprehensive population-based study was performed revealing a 4.4-fold increase in the incidence of paediatric middle-third forearm shaft fractures in the last decade (2000–2009). Further, the increase was still accelerating at the end of the study phase. The finding warrants both tough preventive interventions against these fractures and also justifies aggressive further investigations to reach a full understanding of these harmful injuries.

Forearm shaft fractures are increasingly being treated by operative methods. Operative treatment was performed in 13% of cases in 2000–1 and 52.2% in 2008–9. Non-operative treatment decreased from 87% to 47% in the same time period (P=0.015).

A third of all forearm shaft fractures were caused by one single recreational activity: trampolining. Trampolining was still increasing as a cause of the fractures. Other reasons for the fractures were also increasing, but proportionally they were decreasing (P=0.004). It is concluded that parents should take close care of their children and control their trampolining in order to prevent forearm shaft fractures. At a population level, primarily intervention to decrease children’s forearm shaft fractures should be of a nature that protects children from trampoline injuries.

Diaphyseal forearm fractures were most common in August. The reason for the seasonal variation remains mysterious. Most of the fractures in the summer occurred on dry, moderately windy and warm days. Statistically, dry weather increased the risk of a fracture 1.5-fold (P=0.048). This finding should be remembered in paediatric trauma units, and they should prepare themselves to receive more of these fractures on dry days than on rainy days.

The short-term outcome of operatively treated middle-third fractures was excellent and there were fewer complications compared with non-operatively treated fractures. The risk of intervention due to re-displacement was nil after operative treatment but it was 30% after closed treatment (P<0.001). According to short-term outcome, it is evident that operative treatment is a superior method in regard to children’s diaphyseal forearm fractures.

However, despite the relatively common short-term complications, non-operative treatment resulted in excellent clinical and radiological outcome in the long term. After 11 years of follow-up all non-operatively treated patients paralleled the randomly selected matched control cases. This means that one should not dodge the traditional non-operative treatment. Even if the immediate
result of internal fixation appears to be superior to that of non-operative treatment, the latter will also result in excellent outcome in the long run. In practice, a paediatric orthopaedic surgeon must select the type of treatment keeping in mind these two opposite findings.
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