

REVIEW ARTICLE

The Treatment of Upper Limb Fractures in Children and Adolescents

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SUMMARY

Background: The treatment of fractures in children and adolescents must be based on an adequate knowledge of the physiology of the growing skeleton. Treatment failures usually do not result from technical deficiencies, but rather from a misunderstanding of the special considerations applying to the treatment of fractures in this age group.

Methods: We selectively reviewed recent publications on the main types of long bone fracture occurring in the period of skeletal development.

Results: Alleviating pain is the first step in fracture management, and due attention must be paid to any evidence of child abuse. The goals of treatment are to bring about healing of the fracture and to preserve the function of the wounded limb. The growth that has yet to take place over the remaining period of skeletal development also has to be considered. Predicting the growth pattern of fractured bones is a basic task of the pediatric traumatologist. During the period of skeletal development, conservative and surgical treatments are used in complementary fashion. Particular expertise is needed to deal with fractures around the elbow, especially supracondylar humeral fractures, displaced fractures of the radial condyle of the humerus, radial neck fractures, and radial head dislocations (Monteggia lesions). These problems account for a large fraction of the avoidable cases of faulty fracture healing leading to functional impairment in children and adolescents.

Conclusion: The main requirements for the proper treatment of fractures in children and adolescents are the immediate alleviation of pain and the provision of effective treatment (either in the hospital or on an outpatient basis) to ensure the best possible outcome, while the associated costs and effort is kept to a minimum. Further important goals are a rapid recovery of mobility and the avoidance of late complications, such as restriction of the range of motion or growth disorders of the fractured bone. To achieve these goals, the treating physician should have the necessary expertise in all of the applicable conservative and surgical treatment methods and should be able to apply them for the proper indications.

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Fractures occur more often in the pediatric age group than in healthy adults (1, e1). One reason for this is that children and adolescents are less skilled at risk assessment (e2, e3). Furthermore, bone is less stable—albeit much more elastic—during skeletal development than in adulthood. These properties explain both the higher incidence and the more rapid healing of fractures in children and adolescents. The skeleton is a dynamically growing organ whose growth characteristics and reactions to trauma are well known (2–4, e4). Treatment of fractures in young patients demands precise knowledge of the radiographic anatomy and growth characteristics of healthy and damaged bones as well as the specific fracture dynamics in this age group (e5). Nevertheless, a glance at the figures from the arbitration committees of the German Medical Associations clearly shows that children are too often treated as though they were simply small adults. A higher than average proportion of complaints connected with treatment of fractures occurring during the period of skeletal development are sustained. Confirmed errors include:

- Imprecise clinical assessment
- Misinterpretation of the radiographic findings
- Inappropriate choice of conservative or surgical treatment
- Absent or inadequate follow-up.

The highest error rate (77%) was found for fractures in the region of the elbow joint.

In this article we review the epidemiology, diagnosis, treatment, and aftercare of fractures in children and adolescents, analyzing published reports and drawing on our own data and experience. We focus on fractures of the long bones of the upper limb. The article is intended to acquaint its readers with the specific characteristics of fractures in the pediatric age group and enable them to recognize cases in which specialized treatment is necessary.

Method

This article is based on our own personal experience and on a selective review of the literature. The Medline and Cochrane databases were searched for publications featuring various combinations of relevant terms. Documents published in the past 10 years were preferred (89%), but fundamental studies from the second half of the 20th century were also included. Evidence-based clinical studies on the treatment of fractures

TABLE 1

Distribution of fractures of the long tubular bones during the period of skeletal development

Two-digit fracture site code	Region	Number	Percentage
1.1.	Proximal humerus	73	4.1
1.2.	Humeral diaphysis	20	1.1
1.3.	Distal humerus	278	15.6
2.1.	Proximal forearm	68	3.8
2.2.	Diaphyseal forearm	193	10.8
2.3.	Distal forearm	728	40.8
Sum	Upper extremity	1360	76.3
3.1.	Proximal femur	11	0.6
3.2.	Femoral diaphysis	57	3.2
3.3.	Distal femur	25	1.4
4.1.	Proximal lower leg	36	2.0
4.2.	Diaphyseal lower leg	128	7.2
4.3.	Distal lower leg	166	9.3
Sum	Lower extremity	423	23.7
Total		1783	100

The two-digit fracture site codes are identical in the AO and Li-La classifications. The data are modified from (9). AO, Arbeitsgemeinschaft Osteosynthese—Association for the Study of Internal Fixation; Li-La, Light and Laughter for Sick Children—Efficiency in Medicine

during the period of skeletal development often focus on pain management, plaster configuration, or surgical technique (5–7). Randomized studies and meta-analyses on these aspects of treatment are less common (e6–e11). Most publications are treatment studies with level IV evidence.

Results

Epidemiological data and classification

Comparison of epidemiological data from historical studies with our own data shows a similar distribution of the various fractures (Table 1) (8). Male children and adolescents are affected more frequently, linked with their higher levels of activity and risk-taking (1, e2). There are higher than average rates of metaphyseal and diaphyseal fractures (90%). The customary classifications were used (AO, Arbeitsgemeinschaft Osteosynthese—Association for the Study of Internal Fixation; Li-La, Light and Laughter for Sick Children—Efficiency in Medicine) (2, 4, 9, 10).

Circumstances of injury

The case history must reveal an adequate explanation for the fracture. It is particularly important in young patients to distinguish accidents from non-accidental injuries (pathological fracture, child abuse). If trivial trauma results in broken bones, pathological fractures (e.g., in the presence of juvenile bone cysts), albeit rare,

have to be excluded. Delayed presentation, shaft fractures in infants who are not yet walking, and inconsistent or contradictory accounts of what happened point to child abuse. Typical patterns of injury in child abuse are metaphyseal fractures or bone fragments, subperiosteal hematomas, and fractures of different ages (11, e12–e14).

Diagnosis and fracture types

Clinical examination is initially restricted to inspection. Testing for the primary signs of fracture (abnormal mobility, crepitation) would cause the child unnecessary pain and must therefore be dispensed with (4). The periphery must be investigated for accompanying injuries (blood supply, sensation, and mobility).

The workhorse of fracture diagnosis in pediatric traumatology remains conventional radiography (12). In every case radiographs of the injured site including the neighboring joints are obtained in two projections. The images must be painstakingly analyzed and the fractures examined for signs of instability (e15). Some shaft fractures can be diagnosed reliably by sonography (compression fractures) (e16). Computed tomography and magnetic resonance imaging have no place in acute diagnosis (e17–e19).

Fractures in children and adolescents show typical maturation-dependent characteristics (Table 2). The epiphyseal cartilages act as buffers to axial trauma. Additional torsion or shear forces lead to injury of these growth plates (Table 3) (13, 14).

Growth prognosis

Before planning the treatment of a fracture during the period of skeletal development it is essential to draw up a growth prognosis, so that in the case of displaced fractures both the potential for spontaneous correction and the risk of growth disorder can be assessed (e5). Both of these developments—spontaneous correction and growth disorder—are possible only if the remaining growth period is sufficiently long, and both depend on:

- Age
- Sex
- Stage of development
- Fracture location
- Direction of displacement
- Extent of displacement (4).

The growth dynamics and times of fusion of the various growth plates are known. In the upper extremity, the proximal growth plate of the humerus and the distal plates of the forearm are each responsible for 80% of longitudinal growth in their respective segments of the limb and are late to fuse (at the ages of 14 to 16 and 14 to 18 years, respectively) (3, 4). In the lower limb the growth plates at the knee joint contribute 40% to 60% of longitudinal growth (Figure 1).

If a growth plate contributes intensively to growth over a long period of time, it has a higher potential for spontaneous correction of posttraumatic malalignment, but also higher vulnerability to growth disorders. The

growth plates of the upper limb are less prone to growth disorders and are more likely to correct malalignments (e5, e10, e20–e24). The physes in the lower limb are much more vulnerable to growth disorders. Malalignments in the sagittal plane are corrected better than those in the coronal plane. Rotational deformities are compensated only non-specifically in the context of physiological changes in torsion (4).

Treatment principles

The primary goal of treatment is freedom from pain. Provisional immobilization of the injured limb even before diagnostic investigation provides pain relief and can be supported by medication (non-steroidal anti-rheumatics, opiates) (6, e6, e7, e25). Any painful manipulations, particularly reduction and correction of malalignment, must be carried out with the patient under anesthesia.

Once it has been decided to anesthetize the patient, management must be definitive. Unplanned changes in procedure and repeat interventions should be regarded as complications of treatment. Fragile vital signs or endangered viability of the affected limb require urgent intervention (e26–e28). All other measures can be carried out with less urgency, provided adequate pain treatment is initiated (e29).

Children in unforeseen situations can suffer great distress if separated from their attachment figures (parents), so there should be provision for a parent to stay in hospital with an injured child. Outpatient or short inpatient treatment enables a swift return to the familiar social environment and minimizes stress for the child and the family. The treatment should be designed to support rather than suppress the child’s natural urge to be active (e30).

Treatment methods

Conservative and surgical treatment options are available. The choice of method depends on the extent of primary displacement and on the age, location, and stability of the fracture (e30). Undisplaced or acceptably displaced fractures are treated conservatively. An acceptable displacement is one that will definitely be corrected by the anticipated growth in length and thickness of the injured bone. The literature contains ample information on the correction that can be expected depending on fracture location and patient age (2–4, e5, e22, e23).

If reduction is required, a manipulation technique must be selected that excludes any risk of redisplacement (e31, e32). If this is not possible with immobilization alone, operative stabilization is necessary (e24).

In the epiphysis, joint surface reconstruction can be achieved by means of Kirschner wires or compression screws, usually after open reduction (e33–e37). Arthroscopic monitoring of reduction is also possible. Metaphyseal fragments can usually be reduced well in closed technique, but fixation is often required. This can be attained with Kirschner wires (in which case additional plaster cast immobilization is required) (e11,

TABLE 2

Typical fracture types during the period of skeletal development and their characteristics

Fracture type	Location	Mechanism	Characteristics	Stability
Compression fracture	Metaphysis	Compression	Principally in distal forearm	Stable
Greenstick fracture	Metaphysis, diaphysis	Compression and bending	Cortex interrupted on convex side but preserved on concave side (angulation)	Stable
Bowing fracture	Metaphysis, diaphysis	Bending	As for greenstick fracture, only plastic deformation with no fracture separation	Stable
Complete fracture	Metaphysis	Bending/torsion	Angulation and complete displacement	Unstable
Transverse and oblique fractures (with/without bending wedge)	Diaphysis	Direct trauma with torsion	Complete displacement, angulation, shortening	Unstable
Torsion fracture (with/without bending wedge)	Diaphysis	Indirect trauma with torsion	Displacement, shortening, angulation	Unstable

Assessment of stability, together with the prognosis for growth, determines the treatment plan

e38–e40), with screws, or in individual cases by insertion of an intramedullary rod (19, e41–e43). Diaphyseal fractures are nowadays mostly treated surgically (e30). The method of choice for longitudinally stable transverse fractures is elastic stable intramedullary nailing (ESIN) (e44–e50). The external fixator is an alternative for longitudinally unstable oblique, spiral, or multifragmentary fractures (e5–e53).

Plate fixation is used only occasionally, in adolescents with fractures in close proximity to joints. Interlocking nails are used solely for diaphyseal fractures in patients just before the end of growth (Table 4).

Each method has its own indications. The burden for the patient, the extent and duration of temporary function-limiting malalignments, and individual preferences must always be taken into account.

Follow-up

Compression fractures do not involve displacement, so follow-up radiography is unnecessary (e23). Conservative treatment of unstable fractures can be followed by secondary displacement; therefore, radiographs should be obtained 7 and 28 days after treatment.

Fractures treated by fixation undergo radiological examination 4 weeks after operation and before planned metal removal. Bone healing, range of motion, and load-bearing capacity are assessed by clinical examination. As soon as mobility is almost back to normal, the patient can resume sporting activity.

TABLE 3

Classification of growth plate injuries

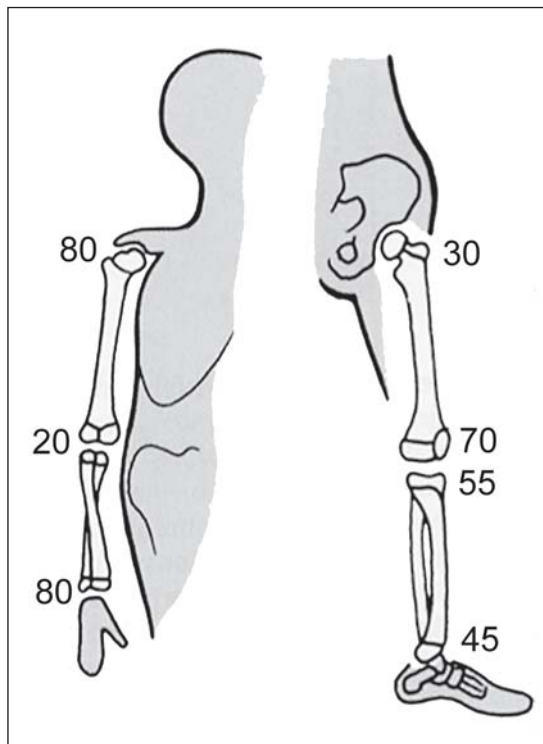
Fracture type	Location	Mechanism	Characteristics	Metaphysis: shaft (S); epiphysis: articular (A)
Harris-Salter I	Metaphysis	Bending/torsion	Physeal separation	S
Harris-Salter II, Aitken I	Metaphysis	Bending/torsion	Physeal separation with metaphyseal wedge	S
Harris-Salter III, Aitken II	Epiphysis	Bending/torsion	Epiphyseal fracture	A
Harris-Salter IV, Aitken III	Epiphysis and metaphysis	Bending/torsion	Fracture across growth plate	A
Harris-Salter V	Epiphyseal growth plate	Crush	Never proved	S

Classification of injuries involving the growth plates according to Aitken (14) and Salter und Harris (15). These are the most commonly used classifications for this region. In the German-language literature, the terms Fugenschaffraktur (growth plate–shaft fracture) and Fugengelenkfraktur (growth plate–articular fracture) (4) highlight the involvement of the metaphyseal or epiphyseal portion of the growth plate

Figure 1:

The growth plates of the long bones do not contribute equally to longitudinal growth. The numbers in this illustration show the percentage contributions of each growth plate.

Plates that contribute a higher proportion of growth also fuse later (from: v. Laer L, Kraus R, Linhart W: *Frakturen und Luxationen im Wachstumsalter*. 5th edition 2007. Stuttgart, New York: Thieme 2007; reproduced by kind permission of Thieme-Verlag, Stuttgart)



Overview of fractures

In the following summary of the principal fractures of the long bones of the upper limb particular attention is paid to the most frequently occurring errors in treatment.

Proximal upper arm

Intra-articular epiphyseal fractures during the period of skeletal development represent a rare occurrence (3, 4). Injuries of this region are mostly physeal separations and metaphyseal fractures with considerable potential for spontaneous correction of up to 40° before adulthood (15, e5, e21, e51). More severely angulated unstable fractures and those displaced by more than the width of the shaft are treated by reduction and ESIN (15, e41, e45). Internal fixation by means of Kirschner wires (instability) or plates (invasiveness) is inappropriate (e54).

Upper arm shaft

Fractures of the shaft of the upper arm are rare. Long oblique or spiral fractures can be treated with plaster or a brace with early resumption of function (15). Axial malalignments of more than 10° will not resolve spontaneously and must be dealt with (4, e4, e54). Transverse fractures are ideal for management with ESIN (e53, e55). The occasionally occurring primary radial nerve palsy does not constitute an indication for surgery per se, as the rate of spontaneous remission is high (e53, e54, e56–e59). Nevertheless, the patients benefit from early physiotherapy after surgical stabilization.

Distal upper arm

The fractures of the distal upper arm most likely to involve complications during the period of skeletal development include supracondylar humerus fracture and radial condyle fracture (16). Because growth at the

plates above and below the elbow joint is only slight, residual malalignments are compensated only in the plane of motion (ante-curvature) up to the 7th year of life (4, 17) and may result in severe restrictions of movement (e39, e40, e60, e61).

Supracondylar humerus fractures are classified by their degree of displacement (grades I–IV [18]). Up to 10% of cases are complicated by primary vascular and neural damage, and 20% of these patients require additional surgical treatment (e62, e63). The goal of reduction is to deal with axial deviations that cannot be corrected spontaneously (varus, valgus, and rotational deformities) (4, e29, e38). Because of the shortness of the joint-bearing fragment, fixation is always indicated in the case of displacement (grade III and IV) (2–4, 7, 19, e38, e64, e65). The options are K-wire osteosynthesis (more stable crossed than unilateral), descending ESIN, and radial external fixator (e39, e45, e52, e64–e73). K-wire fixation involves a 10% risk of damaging the ulnar nerve (e74–e76). The arm must also be immobilized in plaster. In contrast, the technically far more demanding descending ESIN (19) or, as an alternative, the radial external fixator offers primary stability of movement (e72, e77).

Assessment of the radiograph of a reduced supracondylar humerus fracture may be difficult (7, 12, 17, e15). Rotational deformities can be interpreted incorrectly. Unrecognized, they lead to instability and tilting and result in cosmetically bothersome varus deformities (e78–e80) (Figure 2). Intraoperative clinical inspection of the arm axes with control of elbow joint motion is therefore indispensable (20, e81, e82). A number of operations have been reported for correction of the posttraumatic cubitus varus (e83–e89).

Radial condyle fracture is the most common intra-articular fracture during the period of skeletal development (e90, e91). When displaced, such a fracture requires open reduction and stable (tension screw) fixation to avoid pseudarthrosis (e33, e35, e36), which can lead to valgus deformity and secondary instability (e92–e96). Correct primary management is essential, because secondary operative correction yields clinically inferior results (21, e97–e100). Additional diagnostic measures are necessary in primarily non-displaced fractures to exclude secondary dislocation (e92, e94, e96). Since the peak age for lateral humeral condyle fracture is 4 to 5 years, magnetic resonance imaging necessitates anesthesia and thus represents a major intervention.

Sonography (22, e16) may be painful and high-quality devices are not universally available. The diagnostic standard for exclusion of secondary dislocation is therefore plaster-free radiography 4 to 5 days after treatment—this follow-up examination is indispensable (2, 4, 12, e81, e94).

Epicondylar avulsion fractures cause no growth disorders (4). The ossific nucleus of the lateral epicondyle must not be misinterpreted as a fracture fragment (e15). If avulsion of the medial epicondyle occurs in the context of dislocation of the elbow, one must exclude the

TABLE 4

Treatment of pediatric fractures

Method	Remarks
Functional	Redression (e.g., collar-and-cuff bandage), functional bandage (Desault, Gilchrist) with acceptable degree of deformity
Immobilization	Plaster cast, conventional (white) or synthetic (rigid or semirigid; if necessary, correction by cast wedging)
Adaptation osteosynthesis (Kirschner wires)	Metaphyseal fractures: additional plaster cast immobilization necessary (unstable)
Screw fixation	Epiphyseal fractures or physeal separations with metaphyseal wedge after precise reduction
ESIN (elastic stable intramedullary nailing)	In longitudinally stable (transverse) diaphyseal fractures (also greenstick fractures of forearm shaft; as intramedullary rod in proximal upper arm fractures, supracondylar humeral fractures, and radial neck fractures)
External fixator	In longitudinally unstable diaphyseal fractures
Plate fixation	As an exception, in fractures close to joints in adolescents
Medullary or locking nail	In diaphyseal fractures in adolescents

Summary of the standard treatment methods for fractures during the period of skeletal development. In selected individual cases, any methods or implants used in general traumatology (arthroscopy, bone replacement materials, angle-stable plates, etc.) may be employed

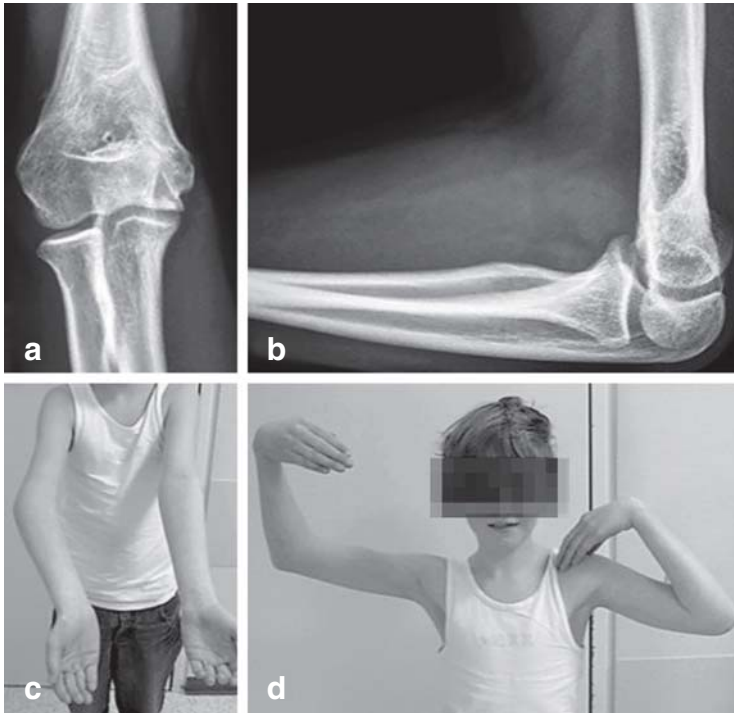


Figure 2: Radiographs and clinical photographs of an 11-year-old boy 2 years after malunion of a supracondylar fracture of the humerus: cubitus varus (a, c), ante-curvature (b), and severe impairment of flexion (d). A varus deformity of this kind is not compensated by growth at any age, the ante-curvature only until the 7th year of life at the latest

presence of a fragment in the joint space (e101). In cases with a tendency to redislocation, e.g., when there is gross displacement, the fragment has to be refixed with the aid of a cannulated screw (e102–e104).

Proximal forearm

Fractures of the proximal forearm are rare, but occur in all age groups. Intra- and extra-articular fractures of the olecranon are found (cave: Monteggia fracture). Intra-articular step-offs are reduced precisely and fixed in place (e105). Almost all fractures of the proximal end of the radius are extra-articular radial neck fractures (4). Although the proximal radial growth plate contributes only a small proportion of the total longitudinal growth, up to the 10th year of life realignment of the growth plate can yield pronounced correction of axial deviations (up to 50°) (23, e106–e108). In older children, axial deviations of over 20° require closed reduction, e.g., by means of ESIN (e42, e43, e45, e109, e110). Elevation by means of the joystick technique (e111) may lead to rupture of the last connecting piece of periosteum that is maintaining the blood supply. Complete dislocation of the radial head necessitates open reduction (23, e43, e44, e107, e108, e111). Intra-articular head fractures occur only after growth is complete.

Common to all injuries in and around the elbow is the fact that physiotherapy is necessary only in exceptional cases; sometimes it may even be counterproductive (e112). Chronic physal separations, periarticular calcifications, and persisting restrictions of movement have been described, but they have to be distinguished from sporadically occurring, non-influenceable aseptic bony necrosis (2–4, e24).

Forearm shaft

Most greenstick fractures occur in the forearm. In up to 30% of cases the bone rebreaks within 12 months because of uneven fracture healing. If the concave side is therapeutically fractured (risk of instability) or the convex side compressed, the incidence of refracture decreases. Complete fractures of the forearm have a high rate of redisplacement (up to 50%) if they are reduced without operative stabilization (4, 24, e46, e113, e114). For this reason such fractures should be managed with ESIN in patients over 3 years of age (24, e115–e118). This surgical intervention is minimally invasive yet yields an optimal treatment outcome with a low rate of complications (e44–e46, e113, e118–e122). Both greenstick and complete fractures may impair pronation and supination of the forearm owing to changes in bony geometry (e123–e127). Post-traumatic axial malalignments should therefore not be left untreated (3, 4, 24, e115, e128, e129).

In the Monteggia fracture, a fracture of the ulna (complete displaced shaft fractures, bowing fracture, olecranon fracture) (e130–e132) is accompanied by dislocation of the head of the radius. Despite the repeated descriptions of this combined injury in the literature, the radial head dislocation is often overlooked (2–4, 12, e4, e130). Therefore, in every patient with a fracture of the ulna, whether diaphyseal or metaphyseal, dislocation of the head of the radius must be actively excluded. On every radiological projection the axis of the neck of the radius is aligned with the center of the capitellum. Fresh radial head dislocations simply require axial correction, sometimes accompanied by ulnar osteosynthesis, but the treatment of old dislocations is elaborate, involving angulation osteotomy of the ulna, and prone to complications (21, e133–e136).

Distal forearm

Compression fractures heal with no problems. They require immobilization in plaster for 2–4 weeks (e9). Radiographic follow-up is unnecessary, as the bony healing can be monitored by clinical examination (e22–e24, e137, e138).

Both greenstick and complete fractures, particularly beyond the metaphysis, tend to angulate and must be checked radiologically at 7 to 10 days after injury (e139). Studies on the management of these very common fractures show a high rate of redisplacement after conservative treatment and a high complication rate for K-wire fixation (e140–e143). Some authors advocate encasing the whole arm in plaster, but this seems to have no advantage over a forearm cast (e8, e99, e144).

A Cochrane Review showed a tendency towards swifter healing after K-wire fixation (5). Up to the 10th or even 12th year of life the distal radius has a particularly marked potential for spontaneous correction of post-traumatic deformities (e20, e145). Corrections of up to 50° have been observed (4). However, it may not be reasonable to expect the patient and his/her family to put up with a bayonet deformity for a period of several months, so this decision should be discussed with all involved (e10, e22).

Conclusion

This review of the treatment principles for fractures of the long bones, particularly those in the upper limb, during the period of bony growth can do no more than give an impression of the depth of knowledge of the physiology of skeletal development that is needed for the proper practice of pediatric traumatology. To do justice to our young patients, we always have to estimate future growth, assessing on one hand the potential for spontaneous correction and on the other the likelihood of growth disorders, taking into account the patient's age, the fracture site, and the direction and extent of displacement. Also important is the ability to work together with the patient and parents in each individual case to achieve an optimal treatment outcome. This requires good communication skills. Possession of the requisite aptitude for correct selection and application of conservative and surgical treatment options is a self-evident requirement. A number of textbooks and compendia on pediatric traumatology—each emphasizing different aspects of the topic—have recently been published in German, giving the interested reader a solid foundation for appropriate and successful treatment of fractures in children and adolescents.

Conflict of interest statement

The authors declare that no conflict of interest exists according to the guidelines of the International Committee of Medical Journal Editors.

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KEY MESSAGES

- Treatment of every fracture starts with appropriate pain therapy.
- A growth prognosis represents an essential basis for treatment planning.
- The pediatric traumatologist must be proficient in the whole spectrum of conservative and surgical treatments—which are complementary rather than competing.
- Most cases of faulty treatment of injuries to the elbow joint are due to incorrect assessment of growth potential, misinterpretation of radiographs, and errors of technique.
- If left untreated, axial malalignments following forearm fractures lead to persisting impairments of pronation and supination; angulated fractures of the distal forearm, on the other hand, are characterized by a considerable potential for correction.

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REVIEW ARTICLE

The Treatment of Upper Limb Fractures in Children and Adolescents

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