The following article discusses how AOCID has developed a system to classify long-bone fractures in children.

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Development and validation of the new AO Pediatric Comprehensive Classification of Long-Bone Fractures (PCCF)

Introduction
Over the last six years, the AO Classification Supervisory Committee (CSC) coordinated by AO Clinical Investigation and Documentation (AOCID), has been active in setting new standards for the development and validation of fracture classification systems. One of the first successful outcomes is the new AO Pediatric Comprehensive Classification of Long-Bone Fractures (PCCF). Presented here are the main features of this new system, as well as the validation steps that were undertaken during its development.

With innovative treatment options made available for pediatric fractures (eg, elastic intramedullary nail with or without the use of end caps) in the last few decades, it has become necessary to implement appropriate clinical data auditing (quality control) and high quality clinical studies to support the surgeons’ decision process. This created an inherent need to develop and validate a comprehensive classification system specifically for pediatric fractures. Initiated by the AO Pediatric Expert Group, and coordinated by the CSC and its AO Pediatric Classification Group, a pediatric comprehensive classification of fractures was developed, taking into consideration the phenomenon of growth and the existing classification. Hence, the current classification proposal is based on the Müller AO Classification for adults and considers child specific relevant fracture features [1–5].

In addition to clinical relevance, scientific validation was paramount. The classification process (ie, fracture diagnosis) should be reliable and valid, therefore it was necessary to start an evaluation early in the development process [6]. As endorsed by the CSC, the development of this classification system successively followed the first two of three research phases recommended by Audigé and coworkers [7] before being considered as validated.

The first development phase involved experienced pediatric orthopedic surgeons who defined a common language to describe pediatric fractures and the process of classification. Four successive pilot agreement studies were conducted to ensure that these terms and process were workable with experts [6, 8]. The second phase involved a web-based multicenter international agreement study involving surgeons with a range of experience [9, 10] to ensure that the system was usable for the non expert surgeon. As these first two phases are completed, recommendations for patient care based on the classification can be developed in the third phase, a prospective clinical study.

The validated classification has been presented at many congresses, has become a standard lecture on AO pediatric courses worldwide, has been published as an appendix in several books [1–3], and will be fully disclosed as a special
chapter of the new Fracture and Dislocation Compendium of the Orthopedic Trauma Association (OTA) [1]. In addition, a new classification brochure has been added to this issue of AO Dialogue.

**Classification overview**

**Location**
Fracture location is related to the four long bones and their three segments, as well as the special pediatric subsegments. The bones and segments within the bones follow a coding scheme similar to that in adults (Fig 1), but the identification of the segments differ. For pediatric long-bone fractures, the end segment has two subsegments: 1, the metaphysic (M) is identified by a square whose side has the same length as the widest part of the physis in question and 2, the epiphysis (E). For the radius/ulna and tibia/fibula bone pairs, both bones must be included in the square. Consequently, the three segments can be defined as:

- Segment 1: Proximal: including epiphysis (E) and metaphysis (M) subsegments
- Segment 2: Diaphysis (D)
- Segment 3: Distal: including metaphysis (M) and epiphysis (E) subsegments

As malleolar fractures are uncommon in children, they are simply coded as distal tibia fractures. For example, the fracture of the medial malleolus is a typical Salter-Harris III or IV fracture of the distal tibia coded as 43.

The original severity coding of A-B-C used in adults is replaced by a classification of fractures according to diaphysis (D), metaphysis (M) and epiphysis (E) (Fig 1). This terminology is known and accepted worldwide and is relevant to pediatric fractures. Epiphyseal fractures (E) involve the epiphysis and respective growth plates (physis); the metaphyseal fractures (M) are identified through the position of the square (where the center of the fracture lines must be located in the square) with one side over the physis. For an easier and more accurate application of the squares and thus, a more reliable classification, a series of predrawn squares are copied on a transparency and applied to the anteroposterior (AP) radiographic view (Fig 2a). This square definition is not applied to the proximal femur, where metaphyseal fractures are located between the physis of the head and the intertrochanteric line.

**Morphology**
The morphology of the fracture is documented by a type specific child code and a severity code, as well as an additional code for displacement of specific fractures (Fig 3).

**Child code**
Relevant pediatric fracture patterns, transformed into a “child code”, are specific and grouped according to each of the fracture location categories of E, M, or D. Internationally known and accepted child patterns have been considered (Fig 4).

Patterns of epiphyseal fractures include the known epiphyseal injuries I to IV according to Salter-Harris [1] using the child codes E/1 to E/4. Other child codes E/5 to E/9 are used to identify Tillaux (two plane) fractures (E/5), tri-plane fractures (E/6), ligament avulsions (E/7), and flake fractures (E/8) (Fig 4).

Three child patterns are identified for metaphyseal fractures, ie, the buckle / torus or greenstick fractures (M/2), complete fractures (M/3) and osteo-ligamentous, musculo-ligamentous avulsion or only avulsion injuries (M/7).

Child patterns within segment 2 (diaphyseal fractures) include bowing fractures (D/1), greenstick fractures (D/2), toddler fractures (D/3), complete transverse fractures (angle ≤ 30° - D/4), complete oblique / spiral fractures (angle > 30° - D/5), Monteggia (D/6), and Galeazzi lesions (D/7).

**Severity**
A grade of fracture severity distinguishes between simple (.1), and wedge (partially unstable fractures with three fragments including a fully separated fragment) or complex fractures (totally unstable fractures with more than three fragments) (.2) (Fig 5).

**Fracture displacement for specific fractures**
Supracondylar humeral fractures (code 13-M/3) are given an additional code regarding the grade of displacement at four levels (I to IV) (Fig 6).

Radial head fractures (code 21-M/2 or /3, or 21-E/1 or /2) are given an additional code (I–III) regarding the axial deviation and level of displacement.

- I = no angulation and no displacement
- II = angulation with displacement less than half of the bone diameter
- III = angulation with displacement more than half of the bone diameter

**Paired bones**
Except for the known Monteggia and Galeazzi lesions, when paired bones (ie, radius/ulna or tibia/fibula) are fractured with the same child pattern, a single classification code should be used with the severity code being used to describe the worst
Fig 1 Fracture location related to bone segments and subsegments. For children, the square must be placed over the larger part of the physis.

Fig 2 Two possibilities to apply the square definition in classifying a fracture as epiphyseal (E), metaphyseal (M), or diaphyseal (D). The metaphysis is identified by a square whose side has the same length as the widest part of the bone physis on the AP radiographic view. For the bone pairs (ie, radius/ulna and tibia/fibula), both bones must be included in the square.
   a) Using a transparency sheet and applied over the x-ray.
   b) Drawing a square over the radiographic image directly by computer.

Fig 3 Overall structure of the pediatric fracture classification.

E = Epiphysis

| E1 | Salter-Harris I |
| E5 | Tillaux (two-plane) fractures |
| E2 | Salter-Harris II |
| E6 | Triplane fractures |
| E3 | Salter-Harris III |
| E7 | Ligament avulsions |
| E4 | Salter-Harris IV |
| E8 | Flake fractures |
| E9 | Other fractures |

M = Metaphysis

| M2 | Incomplete fracture (Torus/Buckle or greenstick) |
| M3 | Complete fracture |
| M7 | Ligament avulsion |
| M9 | Other fractures |

D = Diaphysis

| D1 | Bowing fractures |
| D5 | Complete oblique/spiral fracture > 30° |
| D2 | Greenstick fractures |
| D6 | Monteggia lesion |
| D4 | Complete transverse fracture ≤ 30° |
| D7 | Galeazzi lesion |
| D9 | Other fractures |

Fig 4 Definition of child patterns for epiphyseal (E), metaphyseal (M), and diaphyseal (D) fractures.
Fig 5  Severity implies anticipated difficulties and method of treatment, not the prognosis.

Fig 6  Classification algorithm for coding the displacement of supracondylar humeral fractures.

Fig 7  Example of a supracondylar fracture (a) and a tibia shaft fracture (b).

Fig 8  Screen shot of the COIAC version 2.0 software—Comprehensive Injury Automatic Classifier—for the classification of pediatric fractures.

Stable fractures

Type I

Incomplete fracture. Rogers’ line still intersects the capitellum. In the AP view there is no more than 2 mm valgus/varus fracture gap.

Type II

Incomplete fracture. Rogers’ line still intersects the capitellum and in the AP view there is no more than 2 mm valgus/varus fracture gap.

Unstable fractures

Type III

Complete fracture—no bone continuity (broken cortex), but still some contact between the fracture planes.

Type IV

Complete fracture—no bone continuity and no contact between the fracture planes.

START

No bone continuity (broken cortex)

YES

NO

Complete fracture

Still some contact between the fracture planes, independent of the type of displacement

YES

NO

of the two bones. When a single bone is fractured, a small letter describing that bone (i.e., “r”, “u”, “t”, or “f”) should be added after the segment code (e.g., the code “22u” identifies an isolated diaphyseal fracture of the ulna).

When paired bones are fractured with different child patterns (e.g., a complete fracture of the radius and a bowing fracture of the ulna), each bone must be coded separately including the corresponding small letter (22r-D/5.1 and 22u-D/1.1). This allows for the detailed documentation of combined fractures of the radius and ulna, or those of the tibia and fibula in clinical studies, so their relative influence on treatment outcomes can be properly evaluated. A list of the most frequent combinations of paired fractures is presented at the end of this chapter.
Some further rules

- Fractures of the apophysis are recognized as metaphyseal injuries.
- Transitional fractures with or without a metaphyseal wedge are classified as epiphyseal fractures.
- Ligament avulsions:
  Intraarticular and extraarticular ligament avulsions are epiphyseal and metaphyseal injuries, respectively. The side of ligament avulsion fractures of the distal humerus and distal femur is indicated by the small letter “u” (ulnar/medial), or “r” (radial/lateral) for the humerus and by “t” (tibial/medial), or “f” (fibular/lateral) for the femur.
- Femoral neck fractures:
  Epiphysiolysis and epiphysiolysis with a metaphyseal wedge are coded as normal type E epiphyseal SH I and II fractures E/1 and E/2. Fractures of the femoral neck are coded as normal type M metaphyseal fractures coded from I to III.
  The intertrochanteric line limits the metaphysis.

The full classification code therefore includes five or six descriptive entities depending on the use of a code for fracture displacement. Two typical classification examples are presented in Figure 7.

Outlook
This AO Pediatric Comprehensive Classification of Long-Bone Fractures (PCCF) has been approved by the AO Classification Supervisor Committee and endorsed by the Orthopedic Trauma Association. While further validation work is ongoing, particularly for the displacement coding of supracondylar fractures, this system has already gained international acceptance. To promote its dissemination, training and use, it has been integrated together with the Müller AO Classification into a software package (COIAC version 2.0 - Comprehensive Injury Automatic Classifier) that is now available to all surgeons (www.aofoundation.org/aocoiac).

Using the software, a skeleton interface provides access to bone specific classification modules, whereby successive dropdown menus and classification options aid the classification and coding process (Fig 8). Classification data and additional clinical information can be saved into a relational database that has been further developed to document treatment options and outcomes in a range of clinical settings, as part of the third and last phase of validation.

Bibliography


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