REVIEW ARTICLE

Universal Long Bone Nonunion Classification

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Abstract

Aim and background: The management of bone union disorders is a complex problem in orthopaedics, requiring a reliable and comprehensive classification system for accurate diagnosis and treatment. Despite advances in understanding pathophysiology, diagnosis, and treatment in this area, there is no generally accepted classification system. The aim of our work was to create a comprehensive classification, which will systemize the vast majority of bone union disorders, underline their differences and form the basis for their treatment.

Methods: The key criteria for nonunion evaluation and treatment were identified based on the conducted literature review: Time from the initial event (delayed union or nonunion), location, type of pathology (A, Hypertrophic; B, Normotrophic; C, Oligotrophic) and the presence of hardware. Based on these criteria the ULBNC has been developed. Atrophic nonunions were excluded from this classification as they are considered segmental bone defects with special classification.

Results: The ULBNC is based on the same principles of coding as the "gold standard" AO/OTA Fractures Classification system with alpha-numeric coding "from simple to complex." The choice of treatment method depends on the type, group, and subgroup of the nonunion as described.

Conclusion: Universal Long Bone Nonunion Classification (ULBNC) is an alphanumeric system that describes the localization, type of pathology and morphologic characteristics of a nonunion. The use of ULBNC in practice and research will optimize and standardize the treatment of various types of bone healing disorders and eventually improve clinical outcomes.

Keywords: Aseptic nonunion, Atrophic nonunion, Bone defect, Bone loss, Classification, Hypertrophic nonunion, Nonunion, Normotrophic nonunion, Oligotrophic nonunion, Pseudarthrosis.

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Introduction

Nonunion is a major complication after fracture fixation in orthopaedic trauma and remains a difficult management problem. Impaired fracture healing processes account for about 5–10% of long bone fractures, although this value can vary significantly depending on various factors.[1]

Despite the growing availability of treatment options, nonunion continues to be a highly contentious condition among orthopaedic surgeons. Accordingly, there is no consensus regarding its classification and treatment.[2–4]

The radiological classification of Weber and Cech, developed in 1976, is the most commonly used classification that divides nonunions into hypertrophic, oligotrophic, and atrophic.[5] Hypertrophic nonunions are considered to be hypervascular and with preserved biological healing potential, while atrophic pseudarthrosis is considered to be avascular with impaired biological status.[6]

However, several studies have recently shown that there is no definitive correlation between radiographic features and vascularization and that atrophic nonunions are not necessarily avascular.[7–9] Over the years, other classifications have been proposed that consider bone loss, septic status, or stability.[10–13]

Although all these systems take into account the useful elements of the clinical assessment of nonunions, they consider them individually and separately, thus ignoring the interactions and many other factors aetiologically involved in the onset of impaired bone consolidation.[14] We propose a universal classification through which documentation and research into pathogenesis, diagnosis, treatment and outcomes can be based on.

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Definitions

The following definitions used by the Universal Long Bone Nonunion Classification (ULBNC) play a key role in understanding bone healing disorders and the basic principles of treatment.

- ***Bone healing*** is the physiological process of connecting bone fragments to each other by newly formed bone tissue. The process of bone union consists of 4 stages: (1) inflammation, (2) Soft callus formation, (3) Hard callus formation, (4) Bone remodelling.[1]

- ***Bone union*** is a radiologically documented transition to a bone remodelling phase. Bone union means the bone callus is formed and bone remodelling has started. In primary bone healing, callus formation is not observed and therefore the remodelling phase should start to achieve bone union.
- ***Expected consolidation time (ECT)*** is the time needed for bone union. Different locations and ages have different ECT. Different comorbidities and medications may affect ECT.
- ***Delayed union (DU)*** is the condition when bone union formation has not been achieved within the ECT. Delayed union has the potential (new bone formation, X-ray evidence of dynamic changes, stable fixation) to heal without major surgery within two ECTs. DU may be a pre-nonunion state.
- ***Nonunion (NU)*** means the condition when bone union formation has not been achieved within 2 ECTs. Nonunion has no potential (bone ends resorption, absence of X-ray evidence of dynamic changes, unstable fixation) to heal without major surgery.
- ***Hypertrophic nonunion (HNU)*** is a nonunion characterized by hypertrophic formation of bone at the fracture ends due to insufficient stability.
- ***Normotrophic nonunion (NNU)*** is a nonunion characterized by a "frozen" fracture state without evidence of callus formation or resorption at the bone ends. Usually associated with a mixture of adequate or excessive stability and poor biology.
- ***Oligotrophic nonunion*** is a nonunion characterized by moderate resorption of the bone ends due to instability, malreduction with diastasis and poor biology. 'Atrophic nonunion' is a nonunion characterized by the absence of viable bone ends making contact and having no potential to heal.
- ***Atrophic nonunion*** is essentially a bone defect.[2]
- ***Bone defect*** is a condition not related to time after injury (or other medical condition) but characterized by a lack of viable bone in a location where it is expected to be present.
- ***Minor surgery*** is an intervention not associated with the placement of a new fixation device (or fixator exchange) or bone grafting.
- ***Major surgery*** is an intervention associated with the placement of a new fixation device (or fixator exchange) or bone grafting or both.

General Principles of the Universal Long Bone Nonunion Classification

Universal Long Bone Nonunion Classification consists of using the AO/OTA location and morphology, which is then related to the ECT and consolidation pathology; to this is added previously applied fixation options with all these factors representing the main criteria determining a future treatment approach. Figures 1 to 4 show the formation of a diagnosis using the ULBNC alphanumeric classification code based on the listed criteria.

Location: Bones and Segments

The numeric coding for the site of nonunion corresponds to the coding used in the AO/OTA fracture classification and Universal Long Bone Defect Classification.[2] The numbers 1, 2, 3, and 4 correspond to the humerus, forearm, femur, and lower leg, respectively. Given the presence of two bones in the forearm, the letter R denotes the radius, and the letter U denotes the ulna. Similarly, in the lower leg, the letter T denotes the tibia and the letter F denotes the fibula. After determining the bone involved, the segment is next identified. Segment 1 corresponds to the proximal periarticular region of the bone. Segment 2 corresponds to the diaphyseal region of the bone. Segment 3 corresponds to the distal periarticular region of the bone (Fig. 2). The periarticular segment is defined as per the AO/OTA fracture "square" principle (the side of which is equal to the widest part of the epiphysis of the bone). The diaphyseal segment is then defined as the region between the proximal and distal periarticular segments.

Morphology

Morphology involves classifying bone union disorders by implementation of the three following steps:

1. Determination of the pathology (delayed union or nonunion) based on its duration.
2. Determination of the type of delayed union or nonunion.
3. Determination of the group of delayed union or nonunion.

The groups are different for diaphyseal and periarticular segments. Of note are that types B3 and C3 for diaphyseal segments are divided into two subgroups.

Pathology

The assessment of bone union formation is an important step in making a clinical diagnosis and deciding treatment. In the early stages, observation and non-operative treatment or implementation of minor surgery will achieve bone union. The absence of progress in callus formation on follow-up X-rays indicates the need for more intervention. The first criterion that is important to determine is the time that has elapsed since the fracture. If the fracture has not healed within 1 ECT but has not yet passed 2 ECT, then the diagnosis is a delayed union – DU. It is an ongoing process, the final result of which may be either union or nonunion. With DU, expectant management or minor surgery may

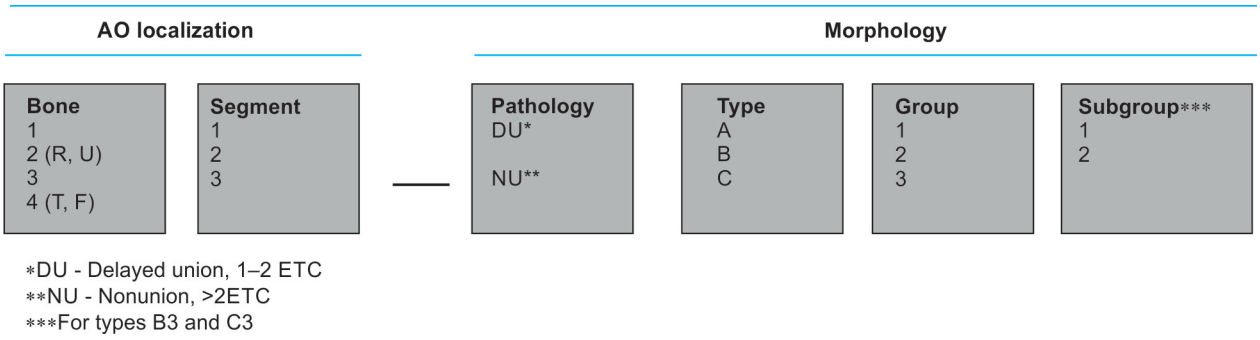

Fig. 1: Nomenclature for use in the universal long bone nonunion classification

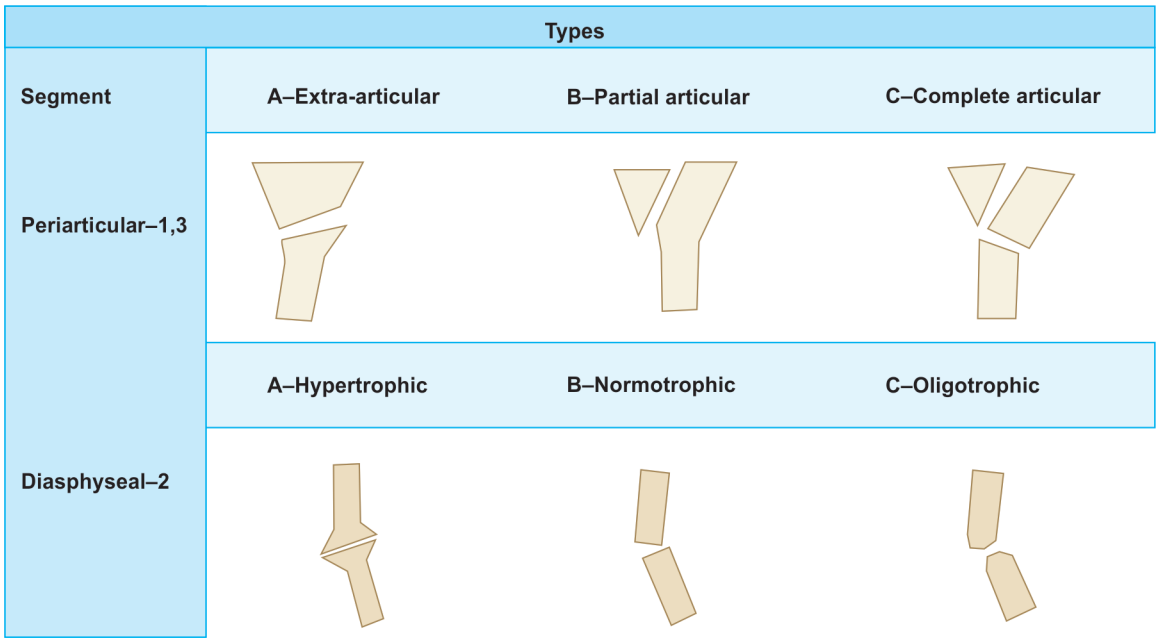

Fig. 2: Types of delayed unions/nonunions

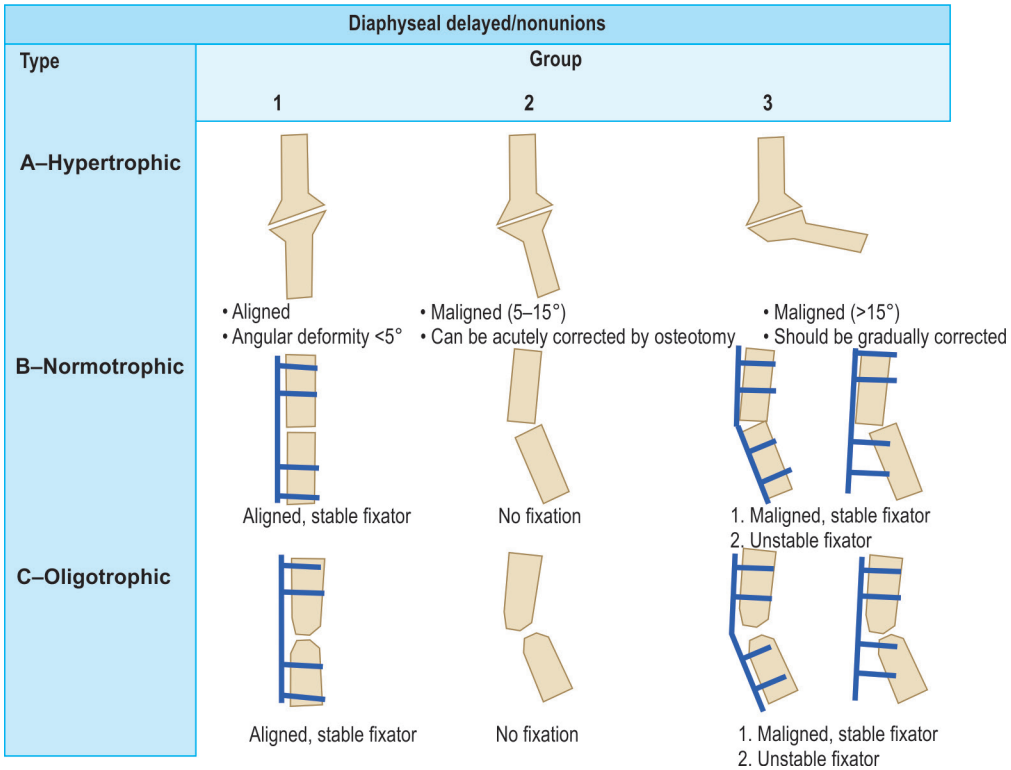

Fig. 3: Groups of diaphyseal delayed/nonunions

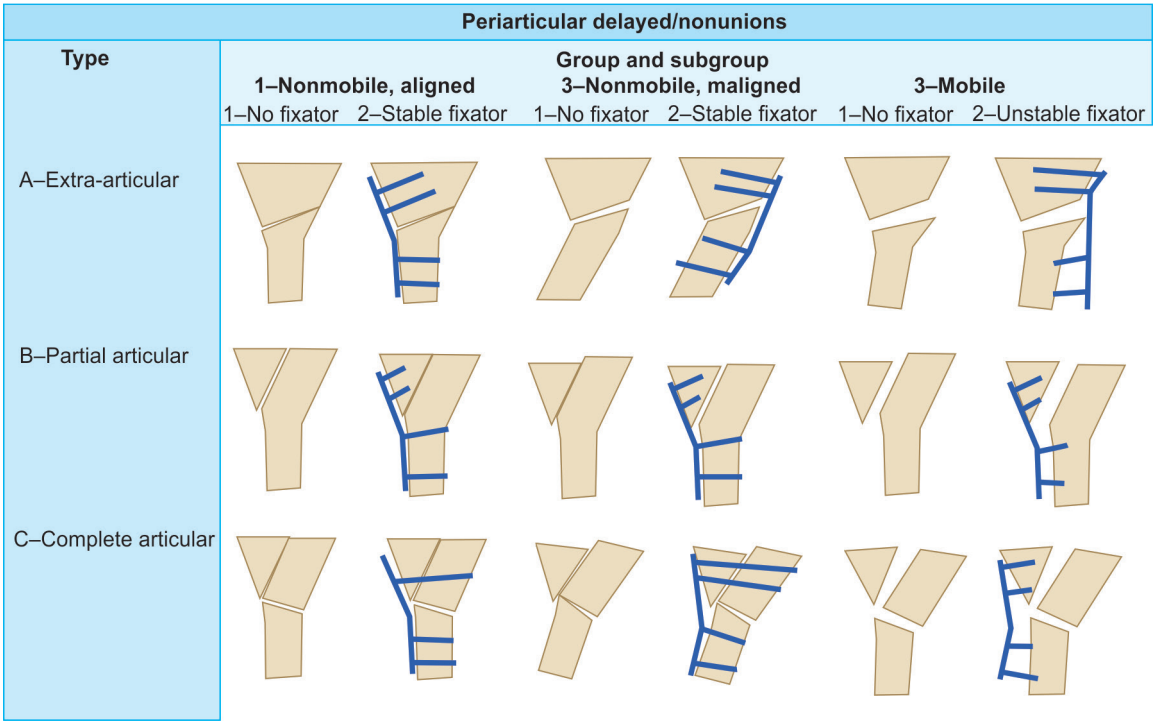

Fig. 4: Groups of periarticular delayed/nonunions

lead to a bone union. If the union does not occur within 2 ECT, then it is then classed as a nonunion. Treatment of NU requires major surgery to 'restart' the fusion process and improve the mechanical or biological conditions or both.

Types

Diaphyseal and periarticular segments have significant biological and histological differences and these are exemplified by their different functions. Therefore, diaphyseal and periarticular delayed or nonunions are divided into different types.

There are 3 types of diaphyseal delayed or nonunions:

1. Hypertrophic
2. Normotrophic
3. Oligotrophic (Fig. 2).

It is important to note that the treatment of atrophic and infected nonunion requires resection of the bone ends until viable tissue is encountered. Thus, atrophic and infected nonunions are essentially segmental bone defects and should be evaluated by use of an appropriate classification.[2]

Periarticular delayed or nonunions are divided into three types by the same principle as periarticular fractures: (1) Extra-articular (2) Partial articular (3) Complete articular (Fig. 2).

Diaphyseal Nonunions

Hypertrophic nonunions (Type A) are caused by suboptimal mechanical conditions while containing adequate blood supply and biology. Such nonunions are characterized by a stiffness in the area of non-union and yet it is not healed; as such these areas are sometimes referred to as having 'stiff mobility' or 'rigid mobility'. Correspondingly, these are called 'stiff' or 'rigid' nonunions. From the clinical point of view, the added presence of deformity and the possibility of correction are of importance. Thus, in the classification, there are three groups of hypertrophic nonunions:

Group A1: Hypertrophic nonunion without deformity or with minimal (up to 5°) deformity, which can be corrected acutely without osteotomy.

Group A2: Hypertrophic nonunion with a deformity that can be corrected acutely by osteotomy (angular deformity 5–15°, malrotation).

Group A3: Hypertrophic nonunion with a deformity that should be corrected gradually with an external fixator (angular deformity more than 15°) with or without osteotomy.

The main aetiological factors leading to the formation of normotrophic (Type B) and oligotrophic (Type C) nonunions are suboptimal biological conditions – poor blood supply, soft tissue interposition, and systemic metabolic disorders. Often the clinical setting is accompanied by suboptimal mechanical conditions. In this regard, when choosing a treatment strategy, it is important to determine whether it is necessary to resolve a biological problem only or additionally improve the fixation and construct stability.

Groups B1 and C1 include nonunions with good alignment and stable fixation. The treatment of such nonunions is based on solving the biological problem only. Augmentation of the fixation method is not necessary but may be performed as an additional option.

Groups B2 and C2 include nonunions without any fixation. Due to the fact that normotrophic and oligotrophic nonunions are mobile, the treatment here will require both biological and mechanical solutions.

Groups B3 and C3 include nonunions requiring a replacement of the previous fixation due to deformity (B3.1 and C3.1) or instability of the fixation (B3.2 and C3.2). Treatment of such nonunions requires addressing both the biological and mechanical issues. At the same time, the presence of a previous fixator may complicate the assessment of the clinical condition and potentially increase the size of surgical intervention or worsen the prognosis or both (Fig. 3).

Periarticular Nonunions

Limb alignment, joint congruency, mobility of the nonunion site and the presence of fixation are the main criteria that should be assessed in periarticular nonunions. The best prognosis for healing and joint preservation is in group 1 nonunions which are non-mobile nonunions with correct alignment and joint congruency that is maintained (A1, Extra-articular, non-mobile, aligned; B1, Partial articular, non-mobile, aligned; C1, Complete articular, non-mobile, aligned). Group 2 nonunions are non-mobile nonunions with malalignment or incongruency or both. The prognosis is good in terms of bone union but deformity correction and joint reconstruction may pose a serious problem. Depending on the presence of fixation in groups 1 and 2, these are divided into 2 subgroups: (1) no fixation (2) stable fixation. The presence of a fixator may yet complicate the evaluation of the nonunion and therefore treatment choices and prognosis. Group 3 nonunions are mobile nonunions, which most often associated with bone resorption, joint destruction, an impaired blood supply and a higher risk of infection. The mobility may be the result of a lack of fixation (subgroup 1) or instability of the device used previously (subgroup 2) (4).

Discussion

Nonunions remain a challenging complication of fracture healing in terms of classification and treatment despite the vast number of proposed classifications and surgical options developed over the past decades. In order to improve the classifications proposed by various authors, there is a need to include the features that appear over time especially when studying the adverse consequences of fractures of the extremities.[6]

The fact that a significant number of classifications have been proposed and there are, in addition, new versions of those reflect the interest of researchers in this problem and indicate the presence of many unresolved issues in the diagnosis and treatment of patients with post-traumatic disorders of bone healing (nonunions).[8,9]

Limitations

The main limitation of this classification system lies in the fact there is a very broad range of potential pathologies that may affect the appendicular skeleton. We have attempted to create a comprehensive classification system that will ultimately capture the vast majority of long bone nonunions but it may be possible that certain subtypes may fall outside of this classification.

Conclusion

The proposed classification is an attempt to classify all types of long bone healing disorders and promote their use in clinical practice and research. This will allow for optimal and standardized treatments for the various types of bone healing problems such as to improve the treatment outcomes.

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