



Original article

<https://doi.org/10.17816/2311-2905-17833>

## Universal Long Bone Defect Classification: Step by Step from Diagnosis to Treatment Strategy and Outcome Assessment. Part 1: Diaphyseal Defects

Leonid N. Solomin<sup>1</sup>, Artem V. Komarov<sup>2</sup>, Anton A. Semenisty<sup>3</sup><sup>1</sup> Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russia<sup>2</sup> Kirov Military Medical Academy, St. Petersburg, Russia<sup>3</sup> Prof. B. Boychev University Hospital for Orthopaedic, Sofia, Bulgaria

### Abstract

This article presents the Universal Long Bone Defect Classification (ULBDC), developed for the standardized description of bone defects, selection of treatment strategy, and assessment of reconstructive outcomes. The current paper focuses on the part of the classification dedicated to diaphyseal defects. The system is based on AO/OTA principles and uses an alphanumeric hierarchical code reflecting localization (bone and segment) and defect morphology (type, group, subgroup, specification) according to the principle “from simple to complex”. To ensure standardized reporting, a unified terminology is proposed to provide precise morphological assessment of bone defects. The following terms are introduced: anticipated bone defect (BDa), cortical bone defect (BDc), and segmental bone defect (BDs). The classification is based on key morphological parameters, including bone integrity (Bi) and defect dimensions (length and width) relative to bone diameter (Bd). For segmental defects, particular attention is paid to shortening (Sh) and diastasis (D). Three types of diaphyseal defects are described: Type A – defects with preserved bone integrity (cortical and anticipated defects), Type B – non-segmental defects (cortical defects with disrupted bone integrity), and Type C – segmental bone defects. The hierarchical structure reflects increasing reconstructive complexity and prognostic severity. The possibility of transforming more complex defects into less complex ones through specific surgical strategies is demonstrated, highlighting the algorithmic value of the system. The ULBDC standardizes terminology, facilitates professional communication, and provides a foundation for the harmonization of clinical research. Despite its relative complexity, the classification demonstrates high reproducibility and practical relevance.

**Keywords:** long bone defects; bone defect classification; diaphyseal defects; cortical bone defect; segmental bone defect; shortening; diastasis.

**Cite as:** Solomin L.N., Komarov A.V., Semenisty A.A. Universal Long Bone Defect Classification: Step by Step from Diagnosis to Treatment Strategy and Outcome Assessment. Part 1: Diaphyseal Defects. *Traumatology and Orthopedics of Russia*. 2026;32(1):203-221. (In Russian). <https://doi.org/10.17816/2311-2905-17833>.

✉ Anton A. Semenisty; e-mail: an.semenisty@gmail.com

Submitted: 01.02.2026. Accepted: 24.02.2026. Published: 27.03.2026.

© Eco-Vector, 2026



## Универсальная классификация дефектов длинных костей: шаг за шагом от диагностики до определения тактики и оценки результата лечения. Часть 1. Диафизарные дефекты

Л.Н. Соломин<sup>1</sup>, А.В. Комаров<sup>2</sup>, А.А. Семенистый<sup>3</sup>

<sup>1</sup> ФГБУ «Национальный медицинский исследовательский центр травматологии и ортопедии им. Р.Р. Вредена» Минздрава России, г. Санкт-Петербург, Россия


<sup>2</sup> ФГБВОУ ВО «Военно-медицинская академия им. С.М. Кирова» МО РФ, г. Санкт-Петербург, Россия


<sup>3</sup> Университетская специализированная ортопедическая больница им. проф. Б. Бойчева, г. София, Болгария

### Реферат

Универсальная классификация дефектов длинных костей (УКДДК) предназначена для стандартизированного описания костных дефектов, выбора тактики лечения и оценки результатов лечения. В данной статье представлена первая часть классификации, посвященная диафизарным дефектам. Система построена по принципам АО/ОТА и включает буквенно-цифровой иерархический код, отражающий локализацию (кость и сегмент) и морфологию дефекта (тип, группа, подгруппа, спецификация) по принципу «от простого к сложному». Для стандартизации описания предложена единая терминология, позволяющая дать точную морфологическую оценку костного дефекта. Введены такие термины, как предполагаемый костный дефект (BDa), кортикальный костный дефект (BDc) и сегментарный костный дефект (BDs). В основе классификации лежат морфологические параметры — непрерывность кости (Bi) и размеры (длина и ширина) дефекта по отношению к ее диаметру (Bd). Для сегментарных костных дефектов особое внимание уделено величине укорочения (Sh) и диастаза (D). В статье рассмотрены три типа диафизарных дефектов: тип А — с сохраненной непрерывностью кости (кортикальные и предполагаемые дефекты), тип В — несегментарные костные дефекты (кортикальные дефекты с нарушением непрерывности кости), тип С — сегментарные костные дефекты. Иерархическая структура классификации отражает возрастание сложности реконструкции и прогностическую значимость дефекта. Продемонстрирована возможность трансформации более сложных дефектов в менее сложные при выборе определенной хирургической стратегии, что подчеркивает алгоритмическую ценность системы. УКДДК обеспечивает унификацию терминологии, облегчает профессиональную коммуникацию и создает основу для стандартизации клинических исследований. Несмотря на относительную сложность, классификация обладает высокой воспроизводимостью и практической значимостью.

**Ключевые слова:** дефекты длинных костей; классификация дефектов; диафизарные дефекты; кортикальный костный дефект; сегментарный костный дефект; укорочение; диастаз.

 **Для цитирования:** Соломин Л.Н., Комаров А.В., Семенистый А.А. Универсальная классификация дефектов длинных костей: шаг за шагом от диагностики до определения тактики и оценки результата лечения. Часть 1. Диафизарные дефекты. *Травматология и ортопедия России*. 2026;32(1):203-221. <https://doi.org/10.17816/2311-2905-17833>.

 Семенистый Антон Алексеевич; e-mail: an.semenisty@gmail.com

Рукопись получена: 01.02.2026. Рукопись одобрена: 24.02.2026. Статья опубликована: 27.03.2026.

© Эко-Вектор, 2026

## INTRODUCTION

Diaphyseal defects of long bones remain among the most challenging conditions in trauma and orthopedic surgery. Their management requires a clinically oriented and reproducible classification system capable of guiding reconstructive decision-making and enabling objective assessment of treatment outcomes [1, 2, 3, 4, 5]. The diversity of etiological factors, together with variations in defect location, size, the presence of shortening, and diastasis, substantially influences therapeutic strategy and prognosis, underscoring the need for a systematic and standardized approach to evaluation.

Existing classification systems address this issue only partially. Our literature review identified 18 different classifications, highlighting the absence of a unified definition and quantitative assessment of long bone defects; most systems are tailored to a specific treatment modality or a particular pathological entity [6].

The classification proposed by B.G. Weber et al. (1976) includes a group of biologically inactive nonunions that morphologically correspond to segmental bone defects. However, it primarily focuses on the biological activity of nonunion and does not provide criteria to guide reconstructive strategy [7].

The Makushin-Shevtsov classification (1996), which incorporates diastasis, shortening, and defect size, is methodologically linked to distraction osteogenesis and therefore lacks universality [8]. Some authors consider defect size alone to be the only clinically relevant parameter for selecting a reconstructive technique [9,10]. Thus, the absence of a generally accepted, systematic classification of long bone defects that incorporates the key parameters determining reconstructive strategy necessitates the development of a universal, clinically oriented system.

In response to this need, the Universal Long Bone Defect Classification (ULBDC) was introduced in 2022. This system integrates assessment of defect location, size, and the degree of shortening/diastasis as the principal determinants of reconstructive management [11]. The present study introduces the second edition of the ULBDC, developed following analysis of its clinical application and subsequent refinement of its classification

criteria [12,13]. The current paper focuses on diaphyseal defects.

## TERMINOLOGY

The terminology used in the ULBDC is fundamental to its interpretation and to the treatment strategies on which it is based. The system incorporates the following key definitions:

- Bone defect (BD) — the absence of bone tissue resulting from trauma or disease, leading to alteration of the anatomical structure, physiology, and function of the limb as an organ of support and movement.

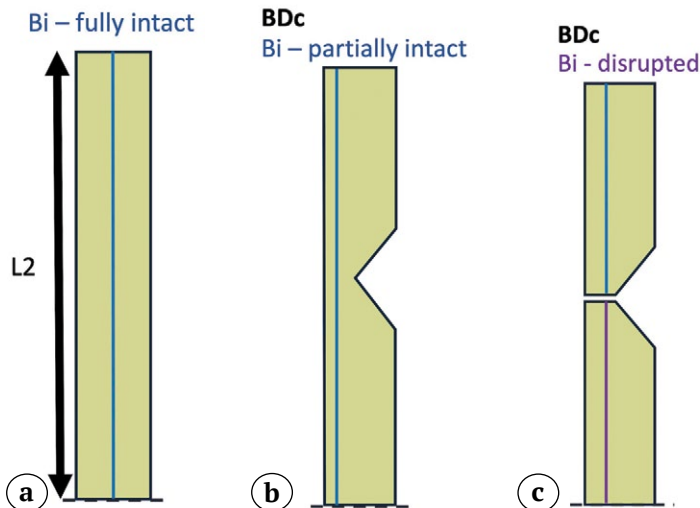
*Morphologically, BD is a lack of bone where it should normally occur. Therefore, the classification includes so-called atrophic nonunions and nonunions with bone loss*

- Bone integrity (Bi) — defined as the continuity of the cortical bone from the proximal to the distal epiphysis (Figure 1). If bone continuity is preserved, i.e., the bone is not divided into separate fragments, Bi is considered intact. When all cortices are preserved, Bi is described as fully intact (Figure 1 a). In the presence of a cortical defect, Bi is considered partially intact (Figure 1 b). When the bone is divided into fragments, with or without diastasis, Bi is regarded as disrupted (Figure 1 c).

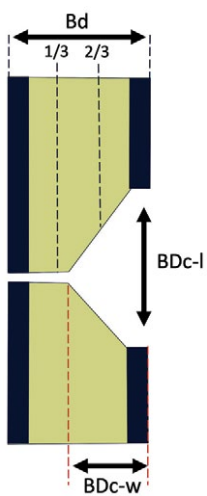
- Cortical bone defect (BDC) — defined as partial loss of cortical bone without shortening of the affected bone; that is, the length of the involved bone (L1) is equal to that of the contralateral bone (L2). In cases of BDC, Bi may be either partially intact or disrupted (Figure 1 b, c). Disrupted Bi in combination with shortening is always classified as a segmental bone defect.

- Bone diameter (Bd) — the distance between the outer boundaries of the cortical bone. For diaphyseal defects, bone diameter is measured at the mid-diaphyseal level (Figure 2).

- Length of cortical bone defect (BDC-l) — the distance between the most proximal and distal margins of the cortical bone defect. In the ULBDC, BDC-l is expressed in relative terms, i.e., in relation to the bone diameter. In clinical practice, absolute values (mm) may also be required, for example when calculating defect volume or planning bone grafting procedures (Figure 2).



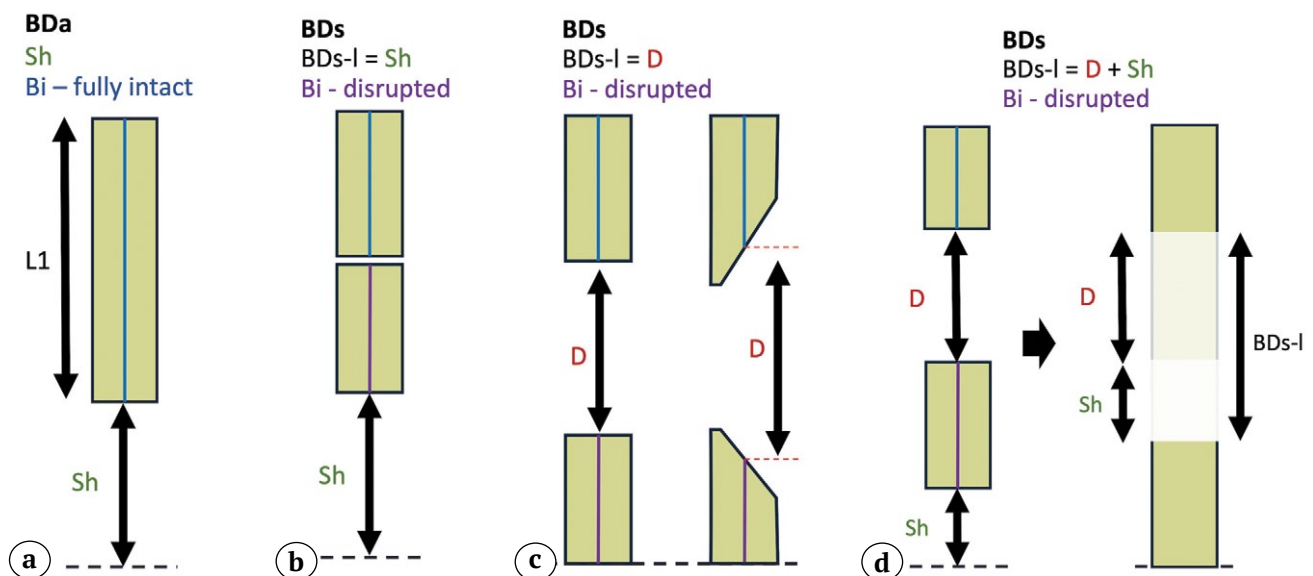
**Figure 1.** Bone integrity (Bi):  
 a – Bi is fully intact, L2 – length of the intact (reference) segment;  
 b – Bi is partially intact;  
 c – Bi is disrupted



**Figure 2.** Morphological characteristics of bone defects:  
 Bd – bone diameter; length (BDC-l) and width (BDC-w) of the cortical bone defect

- Width of cortical bone defect (BDC-w) – assessed in relation to the bone diameter (Figure 2). This parameter forms the basis for subdivision of diaphyseal type B defects into groups and type C2 defects into specifications.

- Anticipated bone defect (BDa) – a deformity or shortening with intact Bi. Osteotomy followed by correction of angular deformity and/or limb lengthening results in disruption of Bi and formation of a true bone defect, which may assume a triangular, rectangular, trapezoidal, or other configuration (Figure 3 a).



**Figure 3.** Segmental and anticipated bone defects: a – anticipated bone defect (BDa): shortening (Sh) with fully intact Bi ( $L1 < L2$ ); b – segmental bone defect (BDs): shortening (Sh) without diastasis, with disrupted Bi ( $L1 < L2$ ), BDC-l – length of the segmental defect; c – segmental bone defect (BDs): diastasis (D) without shortening ( $L1 = L2$ ); d – segmental bone defect (BDs): combined diastasis (D) and shortening (Sh) ( $L1 < L2$ )

- Shortening (Sh) — the difference in length between the affected segment (L1) and the contralateral segment (L2), calculated as  $Sh = L2 - L1$ , irrespective of the presence of inter-fragmentary diastasis (see Figures 2, 3 a, b, d).

*Shortening and angular deformity constitute components of deformity and are morphologically classified as defects*

- Segmental bone defect (BDs) — a bone defect with disrupted Bi, accompanied by shortening and/or diastasis between bone fragments (see Figures 3 b, c, d).

- Diastasis (D) — defined as the extent of the gap between bone fragments. The magnitude of diastasis between two fragments is measured along the mid-diaphyseal axis (see Figures 3 c, d). This is particularly important in cases where the opposing fragment surfaces are oblique.

- Length of segmental defect (BDs-l) — the sum of shortening and diastasis:  $BDs-l = Sh + D$ . If diastasis is absent, the length of the segmental defect equals the amount of shortening. If shortening is absent, the length of the segmental defect equals the magnitude of diastasis (see Figures 3 b, c, d).

### STRUCTURE OF THE CLASSIFICATION

Localization and morphology constitute the principal criteria guiding treatment selection for both diaphyseal and periarticular bone defects. These elements are reflected in the alphanumeric coding system of the ULBDC. Localization is described using the numerical coding system adopted in the AO fracture classification [2]. The first digit of the code designates the bone (1-4), and the second digit specifies the segment (1-3).

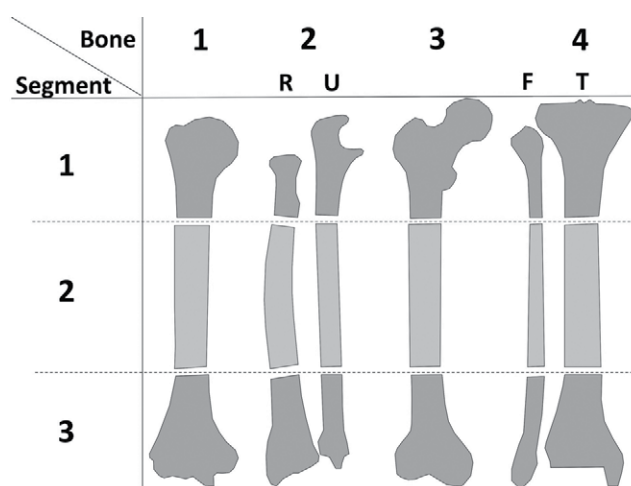
Diagnosis					
Localization		Morphology			
Bone	Segment	Type	Group	Subgroup	Specification**
1	1	A	1	.1	.1 e
2(R,U)	2	B	2	.2	.2 em
3	3	C	3	.3	.3 ed
4(T, F)		D		.4*	.4 m md

**Figure 4.** Alphanumeric structure of the ULBDC  
 \* Subgroup 4 applies only to segmental bone defects (Type C). \*\* Specifications (1-4) apply to diaphyseal defects A2, C2, and C3. Specifications (e, em, ed, m, md) apply to periarticular defects of Types A and B.

Following the numerical localization code, the morphology of the bone defect is classified according to a hierarchical principle, progressing from simple to complex: Type (A-D), Group (1-3), Subgroup (1-4), and Specification (1-4 for diaphyseal defects; e, em, ed, m, md for periarticular defects) (Figure 4).

### LOCALIZATION

In the ULBDC, a bone-segment coding system is used, similar to that of the AO/OTA fracture classification (Figure 5). The periarticular segment is defined according to the “square rule”, in which the side length of the square corresponds to the widest portion of the epiphysis. The diaphyseal segment is defined as the region between the proximal and distal periarticular segments. Unlike the AO/OTA fracture classification, code 44 (malleolar region) is not used in the ULBDC.








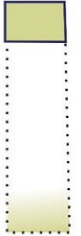






**Figure 5.** Anatomical localization of a bone defect: Bones: 1 — humerus; 2R — radius; 2U — ulna; 3 — femur; 4T — tibia; 4F — fibula. Segments: 1 — proximal periarticular; 2 — diaphyseal; 3 — distal periarticular

### MORPHOLOGY

According to morphological characteristics, bone defects are classified into four Types (A-D), three Groups (1-3), four Subgroups (1-4), and Specifications (1-4 for diaphyseal defects (Figure 6); e, em, ed, m, md for periarticular defects)<sup>1</sup>.

<sup>1</sup>The present article addresses only the classification of diaphyseal bone defects; periarticular defects will be discussed separately in Part II.

Segment	Type			
	A	B	C	D
1 - Proximal	 - Extra-articular	 - Intra-articular	 - Subtotal/total intra-articular	 Amputation Segment 1
2 - Diaphyseal	 - Bone integrity - intact	 - Bone integrity - disrupted - Cortical bone defect	 - Bone integrity - disrupted - Segmental bone defect	 Amputation Segment 2
3 - Distal	 - Extra-articular	 - Intra-articular	 - Subtotal/total intra-articular	 Amputation Segment 3

**Figure 6.** Morphological types of long bone defects

The morphological framework is based on a hierarchical principle progressing from simple to complex, reflecting increasing reconstructive difficulty and a less favorable prognosis with ascending letter rank (Type) and numerical rank (Group and Subgroup). As treatment strategies differ substantially between diaphyseal and periarticular bone defects, the principles governing their subdivision into Types, Groups, and Subgroups also differ.

Defects associated with amputation (Type D) require separate consideration and are not addressed in the present study.

## DIAPHYSEAL DEFECTS

Diaphyseal defects (segment 2) are classified into Types according to the status of bone integrity (Bi).

Type A: bone integrity is fully or partially preserved.

Type B: bone integrity is disrupted; however, the defect does not meet the criteria of a segmental defect. For example, a cortical bone defect resulting from an open fracture may be present without shortening of the segment.

Type C: segmental bone defect characterized by disrupted bone integrity, accompanied by segmental shortening and/or diastasis between fragments.

Each Type is described in detail below.

### Type A

Diaphyseal defects with preserved bone integrity (Type A) include cortical bone defects (BDC) and anticipated bone defects (BDa) (Figure 7).

Cortical defects with preserved bone integrity (A1, A3) may occur, for example, following fracture union with residual cortical bone loss, in superficial or localized osteomyelitis (Cierny-Mader Types II and III), or in certain bone

tumors [14]. Group allocation is determined by calculating the ratio of cortical defect width (BDC-w) to bone diameter (Bd).

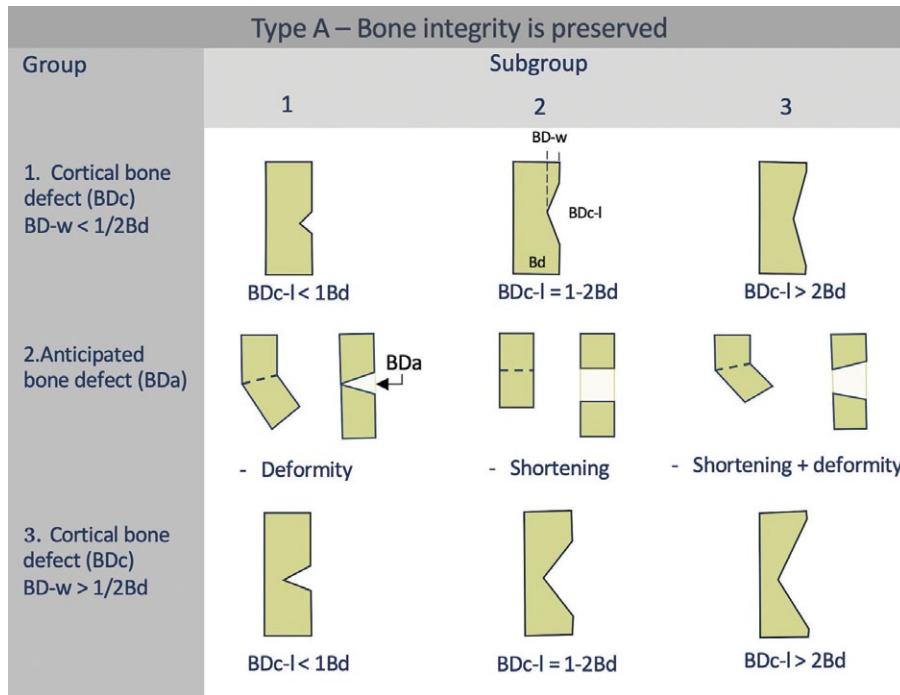
Type A1: cortical bone defect involving  $< \frac{1}{2}$  of the bone diameter.

Type A3: cortical bone defect involving  $> \frac{1}{2}$  of the bone diameter, with intact Bi. These

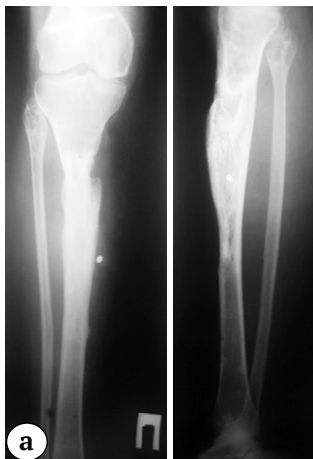
defects are associated with an increased risk of pathological fracture.

Subgroups are defined according to the length of the cortical defect (BDC-l) relative to bone diameter (Bd): 1 —  $BDC-l < 1Bd$ ; 2 —  $BDC-l = 1-2Bd$ ; 3 —  $BDC-l > 2Bd$ .

Representative clinical examples of Type A1 and A3 defects are shown in Figure 8.



**Figure 7.** Type A diaphyseal defects (bone integrity is intact)



a — Type A1.1  
BD 4T2 A1.1 — cortical defect of the tibia following union of an open fracture. The defect width is  $< \frac{1}{2}$  of the bone diameter ( $BDC-w < \frac{1}{2}Bd$ ), and the defect length is  $< 1$  bone diameter ( $BDC-l < 1Bd$ );



b — Type A1.2  
BD 4T2 A1.2 — cortical defect of the tibia following tumor resection with preserved bone integrity. The defect width is  $< \frac{1}{2}$  of the bone diameter ( $BDC-w < \frac{1}{2}Bd$ ), and the defect length ranges from 1 to 2 bone diameters ( $BDC-l = 1-2Bd$ );

**Figure 8 (a, b).** Type A1 (a, b) and A3 (c) diaphyseal defects



c – Type A3.3

BD 4T2 A3.3 – cortical defect of the distal tibia temporarily filled with a cement spacer. The defect width exceeds  $\frac{1}{2}$  of the bone diameter ( $BDC-w > \frac{1}{2}Bd$ ), and the defect length is greater than 2 bone diameters ( $BDC-l > 2Bd$ )

**Figure 8 (c).** Type A1 (a, b) and A3 (c) diaphyseal defects

Deformities and shortening are classified as anticipated bone defects (BDa) and are designated as Type A2. Subgroups of Type A2 include: 1 – angular deformity; 2 – shortening; 3 – shortening + angular deformity.

In anticipated bone defects (Type A2), specifications assist in determining the appropriate deformity correction strategy. Angular deformities (A2.1) are subdivided according to the preferred correction method:

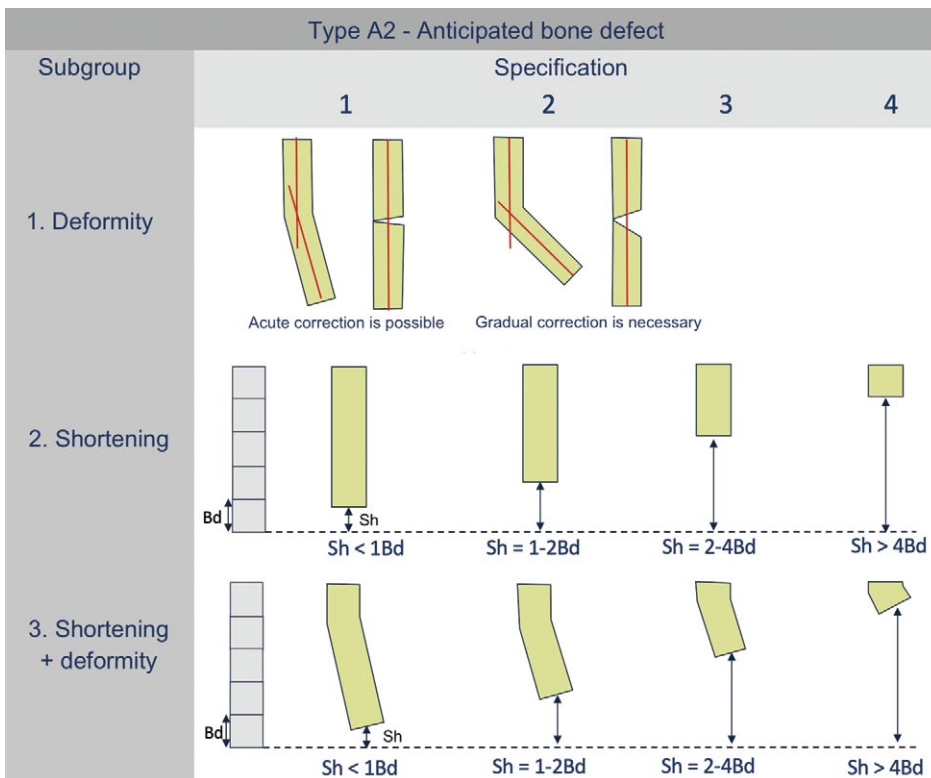
A2.1.1 – deformities suitable for acute (single-stage) correction. A2.1.2 – deformities for which gradual correction is recommended.

A deformity of approximately  $20^\circ$  serves as a conventional threshold between Specifications

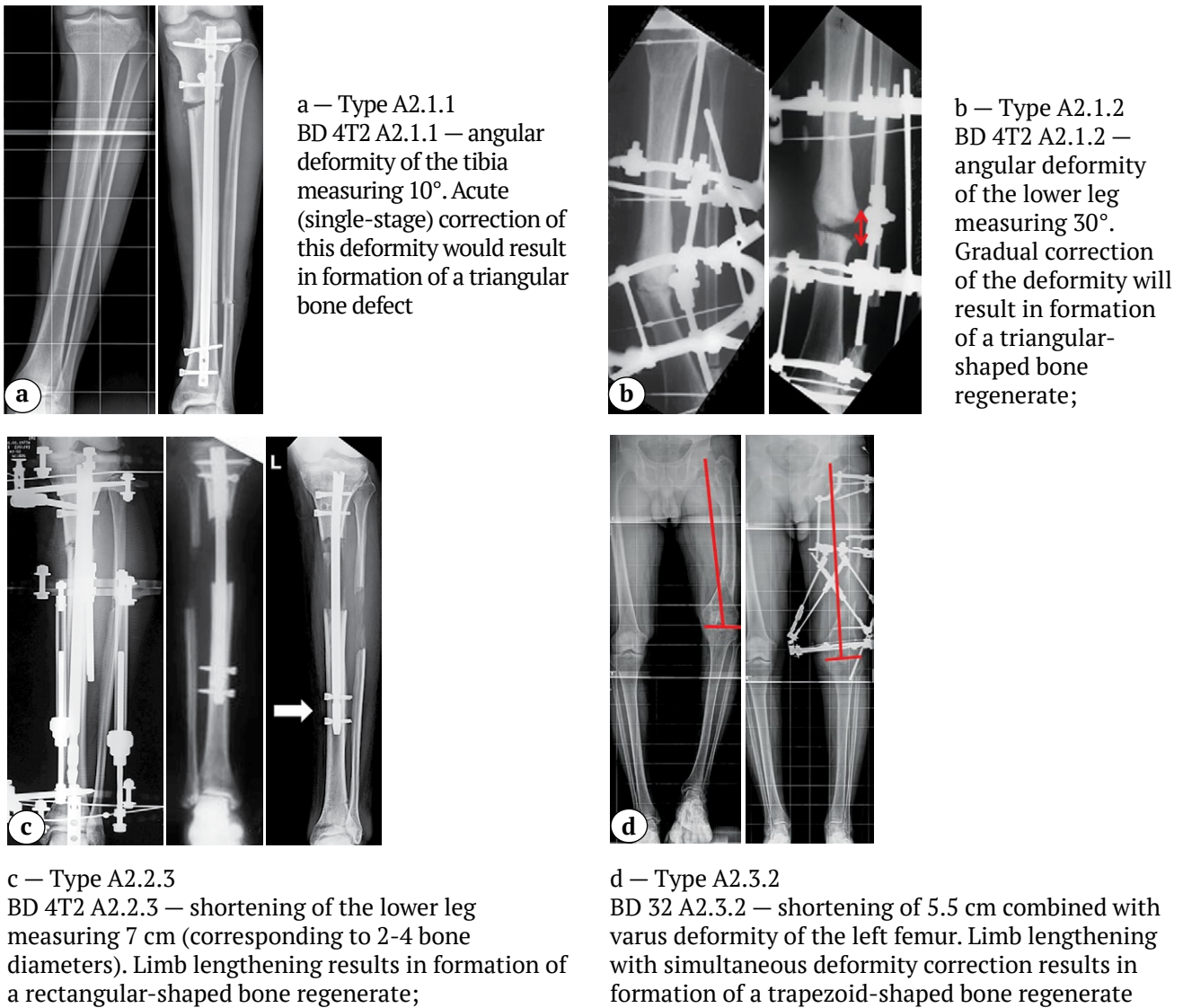
1 and 2. However, this value may vary depending on the clinical context, including the location of the deformity apex, soft-tissue condition, and other patient-specific factors.

Types A2.2 and A2.3 denote shortening of the bone, with or without associated angular deformity. Depending on the magnitude of shortening, these defects are subdivided into the following specifications: 1 – shortening  $< 1$  bone diameter ( $Sh < Bd$ ); 2 – shortening 1-2 bone diameters ( $1Bd < Sh < 2Bd$ ); 3 – shortening 2-4 bone diameters ( $2Bd < Sh < 4Bd$ ); 4 – shortening  $> 4$  bone diameters ( $Sh > 4Bd$ ) (Figure 9).

Representative clinical examples of Type A2 defects are shown in Figure 10.



**Figure 9.** Anticipated bone defects (BDa) – Type A2, Specifications



**Figure 10.** Type A2 diaphyseal defects (anticipated bone defects)

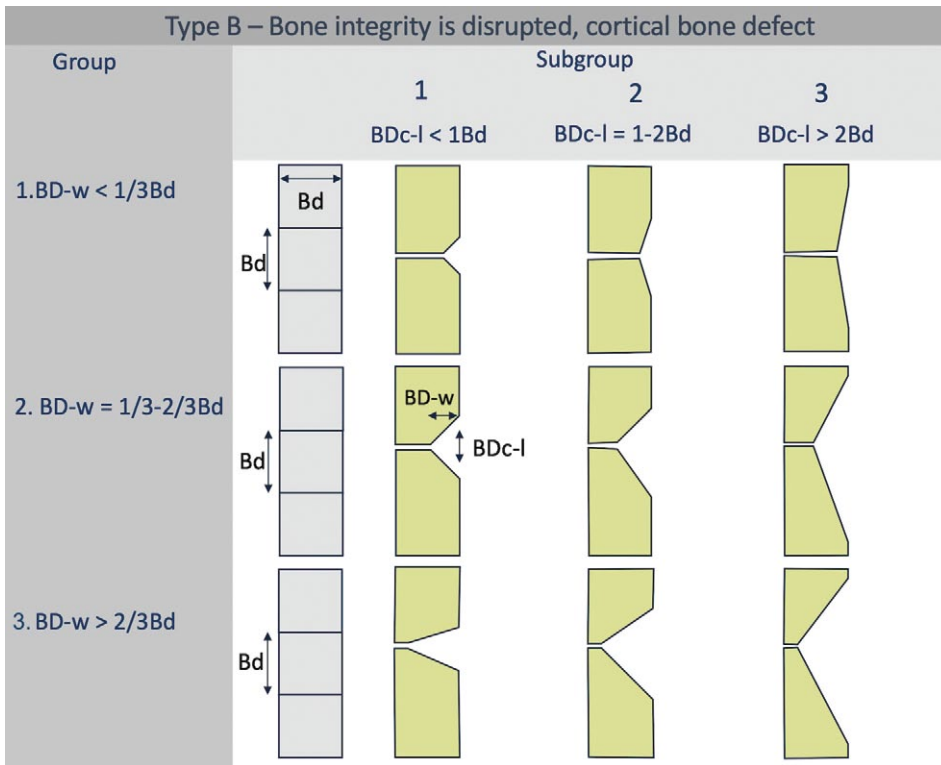
**Type B**

Type B diaphyseal defects comprise cortical bone defects associated with disrupted Bi. These defects are non-segmental and are not accompanied by shortening and/or diastasis. Such defects are commonly observed in open fractures, pathological fractures secondary to bone tumors, and in oligotrophic nonunions (Type C according to the ULBNC classification) [15].

*In atrophic and infected nonunions, there is no contact between viable bone ends; therefore, these conditions should be classified as segmental bone defects (Type C)*

Subdivision of Type B defects into Groups is based on defect width (BDc-w) relative to bone diameter (Bd). Subdivision into Subgroups is determined by defect length (BDc-l) in relation to bone diameter (Bd) (Figure 11). Depending on the Group and Subgroup, treatment may range from stable fixation alone (Type B1.1) to fixation combined with bone grafting (B2.2). In more complex cases (B3.3), advanced reconstructive techniques may be required, including the Masquelet technique or methods based on distraction osteogenesis.

Representative clinical examples of Type B defects are shown in Figure 12.

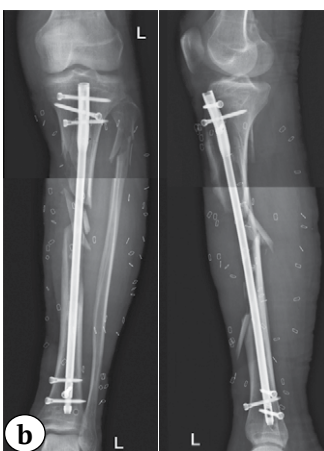


**Figure 11.** Subdivision of Type B diaphyseal defects into Groups and Subgroups



**a** – Type B2.2

BD 4T2 B2.2 – cortical bone defect following an open fracture. The defect width involves 1/3 to 2/3 of the bone diameter (Group 2), and the defect length corresponds to 1-2 bone diameters (Subgroup 2);



**b** – Type B3.3

BD 4T2 B3.3 – cortical bone defect following an open fracture. The defect width exceeds 2/3 of the bone diameter (Group 3), and the defect length is > 2 bone diameters (Subgroup 3). Notably, there is no direct contact between the main bone fragments; however, a potentially viable intermediate fragment remains along the posterior cortex. If union occurs, the defect would be reclassified as a cortical defect with preserved bone integrity (BD 4T2 A3.3). Conversely, in the event of nonunion, the intermediate posterior fragment would be considered nonviable, and the condition would be reclassified as a segmental defect with diastasis (Type C3)

**Figure 12.** Clinical examples of Type B bone defects

**Type C**

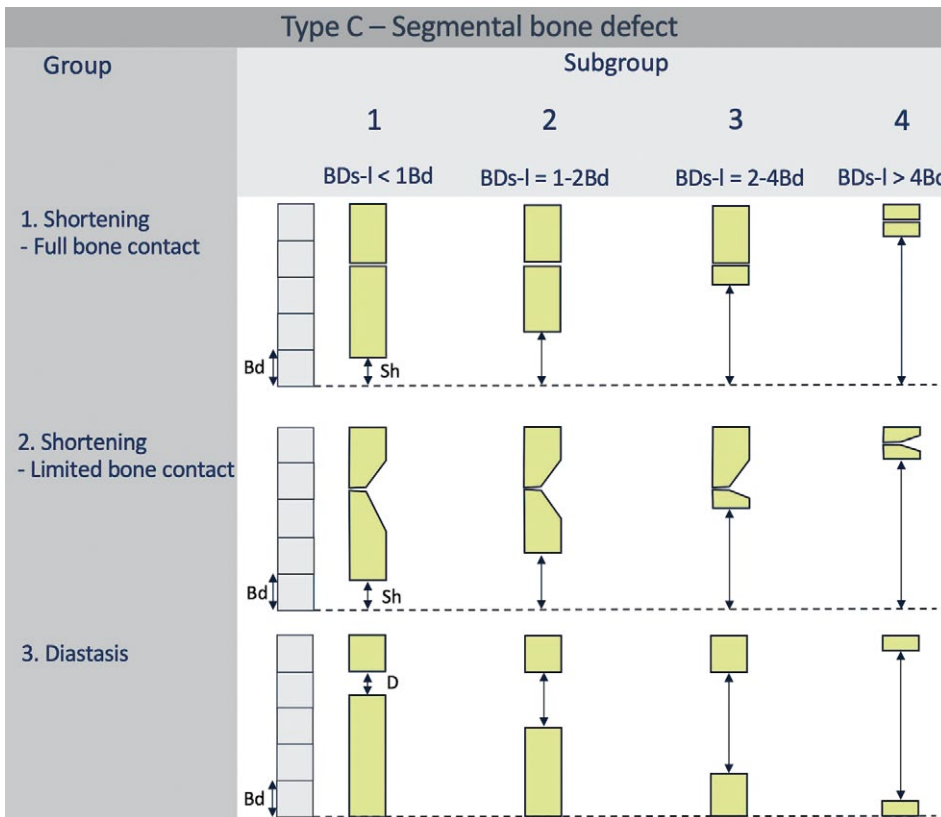
Type C diaphyseal defects represent segmental bone defects (BDs). The presence of shortening (Sh), diastasis (D), and the nature of contact between bone fragments constitute the principal criteria for subdivision of segmental defects into Groups:

- C1 – shortening without diastasis (complete contact between fragments);
- C2 – shortening combined with a cortical bone defect (partial contact between fragments);
- C3 – diastasis, with or without associated shortening.

*Any extra-articular segmental bone defect is classified as Type C, segment 2, even if it extends into the metaphyseal region*

One of the key characteristics of Type C defects is the length of the segmental bone defect (BDs-l), defined as the sum of diastasis and shortening:  $BDs-l = Sh + D$  (see Figure 3).

Based on the magnitude of BDs-l relative to bone diameter (Bd), segmental defects are subdivided into four Subgroups (Figure 13): 1 –  $BDs-l < 1Bd$ ; 2 –  $1Bd < BDs-l < 2Bd$ ; 3 –  $2Bd < BDs-l < 4Bd$ ; 4 –  $BDs-l > 4Bd$ .

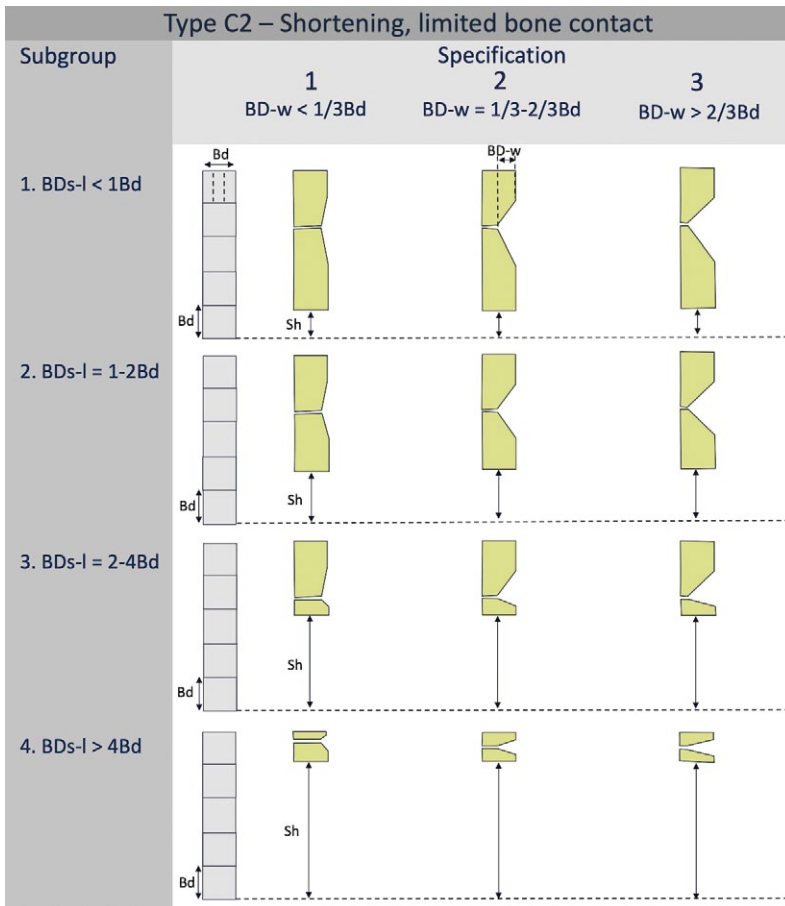


**Figure 13.** Subdivision of Type C diaphyseal defects into Groups and Subgroups

Type C2 defects (shortening combined with a cortical bone defect) represent segmental bone defects with limited contact between fragments. Based on the width of the cortical bone defect (BDc-w), measured in thirds of the diaphyseal diameter (Bd), these defects are subdivided into three Specifications, analogous to the Grouping of Type B defects: 1 – cortical defect width  $< 1/3$

of the bone diameter; 2 – cortical defect width  $1/3-2/3$  of the bone diameter; 3 – cortical defect width  $> 2/3$  of the bone diameter (Figure 14).

*Shortening and angulation performed to approximate bone fragments and facilitate closure of extensive soft-tissue defects result in a condition equivalent to a Type C2 defect*



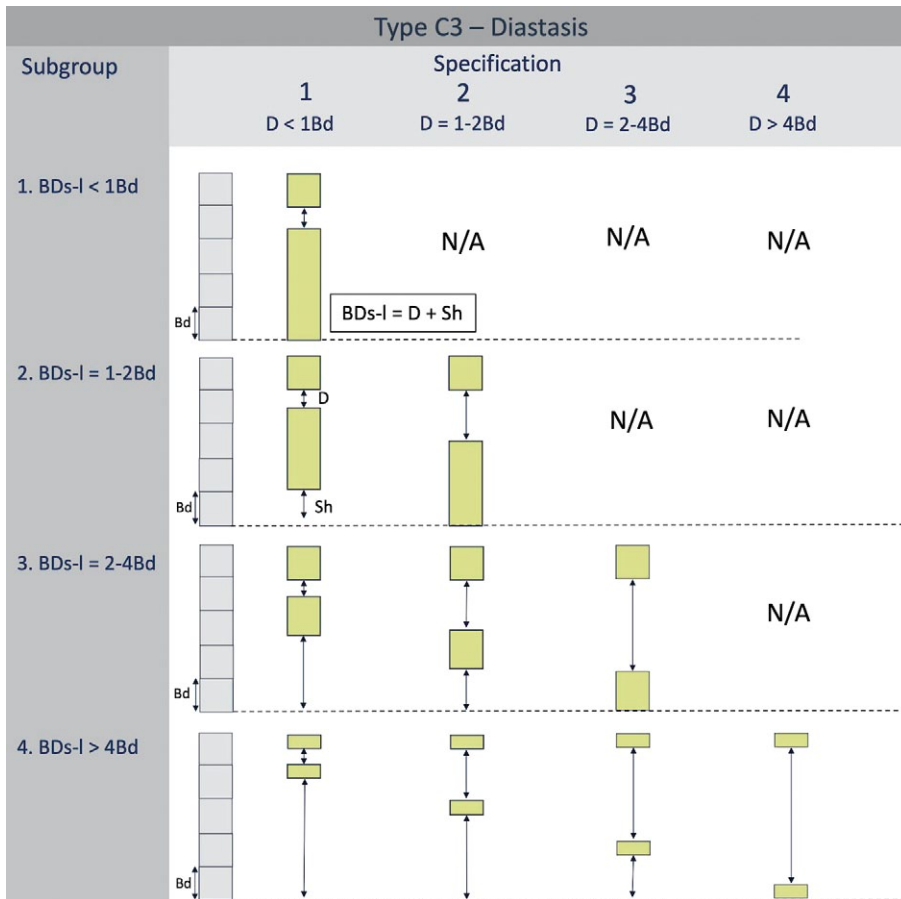
**Figure 14.** Specifications of Type C2 diaphyseal defects (shortening combined with a cortical bone defect; incomplete fragment contact)

Type C3 defects (diastasis with or without associated shortening) represent segmental defects characterized by complete absence of contact between bone fragments, i.e., the presence of diastasis. These defects are further subdivided into four Specifications according to the length of diastasis (D). As the magnitude of diastasis (D) cannot exceed the total segmental defect length (BDs-l), the order of

the Specification cannot exceed the order of the corresponding Subgroup.

Accordingly, C3.1 has only one defining characteristic, which may be omitted, C3.2 has two defining characteristics, C3.3 has three defining characteristics, C3.4 has four defining characteristics (Figure 15).

Clinical examples of Type C defects are presented in Figure 16.



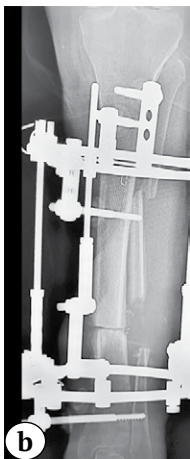
**Figure 15.** Specifications of Type C3 diaphyseal defects (diastasis, with or without associated shortening)



a — Type C3.3.3

BD 4T2 C3.3.3 — bone defect of the left tibia (4T2) associated with osteomyelitis. Although apparent posterior cortical contact is visible on the lateral X-ray, the proximal and distal bone ends are necrotic. The true length of the segmental defect must be determined intraoperatively following resection to viable (“healthy”) bone. After resection, the defect measured 7 cm. This corresponds to a segmental bone defect (Type C) with diastasis (Group 3), measuring 2-4 bone diameters (Subgroup 3), without shortening (Specification 3)

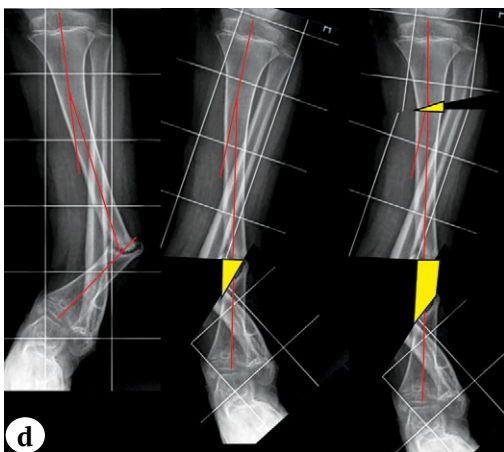
**Figure 16 (a).** Clinical examples of Type C bone defects



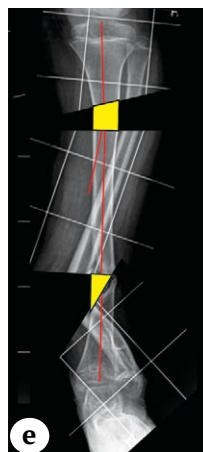
**b** — conversion to Type C1  
Acute shortening of the segment was performed to achieve fragment contact, thereby converting the defect from Type C3.3.3 (segmental defect with diastasis) to Type C1.3.3 (segmental defect with shortening and complete fragment contact), classified as BD 4T2 C1.3.3;



**c** — conversion from Type C1 to Type A2  
Bone union following acute shortening results in formation of an anticipated bone defect, classified as BD 4T2 A2.2.3, requiring planned limb lengthening, as performed in the present clinical case;



**d** — Type C2.2.3  
BD 4T2 C2.2.3 — nonunion of the tibia with 60° deformity and 3 cm shortening (corresponding to 1-2Bd). Bone integrity is disrupted. Following correction of the deformity at the nonunion site, the defect will be characterized by shortening with partial fragment contact, consistent with a Type C2 defect. A compensatory proximal valgus deformity is also present, representing an anticipated bone defect that can be corrected acutely and classified as BD 4T2 A2.1.1;



**e** — Type C2 = B3 + A2  
The same clinical scenario may be interpreted differently if the shortening is transferred to the proximal deformity site. In this case, the nonunion with deformity may be classified as a Type B cortical defect with disrupted bone integrity (BD 4T2 B3.1), while the proximal deformity with shortening would be considered an anticipated bone defect (BD 4T2 A2.3.2), corresponding to 1-2Bd with associated angular deformity;



**f** — Type C3.4.4  
BD 4T2 C3.4.4 — segmental defect of the tibia measuring 14 cm, reconstructed with an allograft. The total segmental defect length exceeds 4 bone diameters, with diastasis also > 4Bd;



**g** — Type C3.4.3  
BD 4T2 C3.4.3 — segmental defect of the tibia measuring 14 cm (> 4 bone diameters). Partial acute shortening does not change the total segmental defect length, but reduces the magnitude of diastasis, thereby lowering the Specification rank from .4 to .3

**Figure 16 (b, c, d, e, f, g).** Clinical examples of Type C bone defects

## DISCUSSION

The Universal Long Bone Defect Classification (ULBDC) is based on the same coding principles as the AO/OTA fracture classification, the current gold standard in fracture taxonomy. It employs an alphanumeric structure progressing from simple to complex, grounded in clinically relevant criteria necessary for treatment decision-making: localization (bone and segment) and morphology (Type, Group, and Subgroup) [2].

For diaphyseal defects, assessment includes defect size, localization, bone integrity, and the presence or absence of fragment contact. Defects with preserved bone integrity generally demonstrate a more predictable clinical course and a more favorable prognosis compared with segmental defects characterized by diastasis.

It should be emphasized that the use of relative measurements (i.e., expressed in relation to bone diameter) provides a more accurate and anatomically appropriate assessment of defect size. Nevertheless, absolute measurements may also be applied within the framework of this classification. For example, a 10 cm segmental defect of the femur ( $Bd \approx 3.5$  cm) or tibia ( $Bd \approx 3.0$  cm) corresponds to 2-4 bone diameters (femur:  $10/3.5 = 2.9$ ; tibia:  $10/3.0 = 3.3$ ), and is therefore classified as Subgroup 3. In contrast, a 10 cm defect of the ulna ( $Bd \approx 1.5$  cm) repre-

sents more than 4 bone diameters ( $10/1.5 = 6.7$ ), corresponding to Subgroup 4.

Accordingly, Table 1 presents the proposed average bone diameter values expressed in absolute terms to facilitate practical application of the classification.

The ULBDC reflects increasing reconstructive complexity and, consequently, a less favorable prognosis with ascending hierarchical rank. This structured alphanumeric coding system not only standardizes the description of clinical scenarios but also serves as an algorithmic guide for treatment selection. This is particularly important in situations where alternative and fundamentally different reconstructive strategies exist.

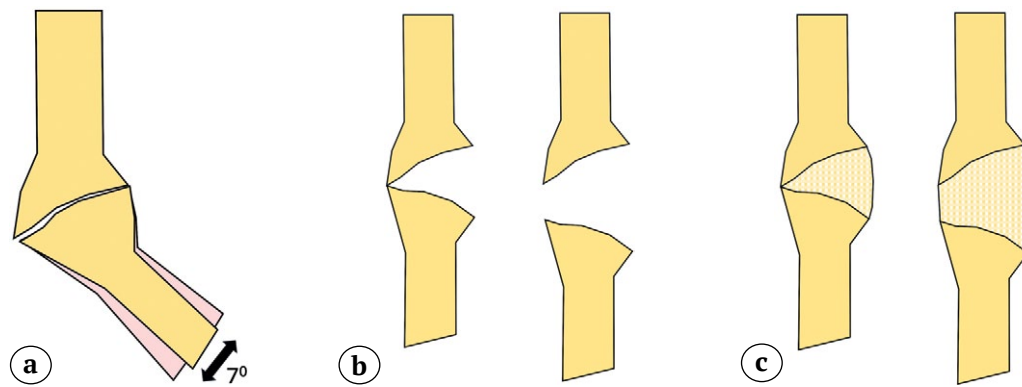
For example, a hypertrophic nonunion may simultaneously represent both a nonunion and a bone defect that becomes apparent during deformity correction. Although bone integrity is technically disrupted (Bi – disrupted), the clinical presentation is characterized by deformity and limited pathological mobility ( $< 7^\circ$ ), with partial preservation of the limb's weight-bearing function.

Acute correction of such deformity without osteotomy is not feasible if the magnitude of deformity exceeds the pathological mobility of the hypertrophic nonunion ( $< 7^\circ$ ) (Figure 17 a). When acute correction with osteotomy is performed at the level of nonunion, a cortical (Type B) or even segmental (Type C) bone defect immediately develops on the concave side of the deformity (Figure 17 b). If deformity correction is performed gradually using external fixation, the condition is more appropriately classified as Type A2 (BDa): a deformity requiring gradual correction, with subsequent formation of a wedge-shaped (A2.1) or trapezoid-shaped (A2.3) distraction regenerate (Figure 17 c).

Table 1

### Reference values of bone diameters expressed in absolute measurements

Localization (bone)	Bone diameter, mm
Humerus	25
Radius/ulna	15
Femur	35
Tibia	30
Fibula	12



**Figure 17.** Hypertrophic nonunion with deformity (pathological mobility  $< 7^\circ$ ) (a); formation of a cortical defect (Type B, left) or a segmental defect (Type C, right) following acute correction (b); anticipated bone defect during gradual correction, with formation of a wedge-shaped regenerate (Type A2.1, left) or a trapezoid-shaped regenerate (Type A2.3, right) (c)

In this scenario, the pathology simultaneously remains a “nonunion” and an “anticipated bone defect”, as the primary goal of intervention is deformity correction and controlled formation of distraction regenerate. Consistent with the classification principle of progression from simple to complex, gradual correction (Type A) is associated with a more favorable prognosis than acute correction resulting in Type B or Type C defects.

Another example of clinical application of the classification concerns treatment strategy selection in complex segmental defects, particularly Type C3 (defect-diastasis) (Figure 18 a).

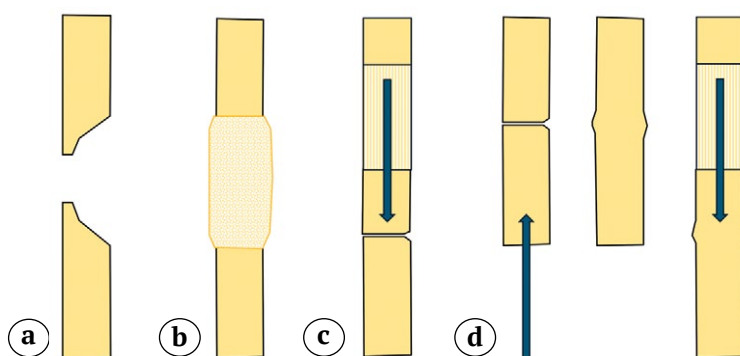
Two principal strategic approaches may be considered:

1. Primary defect reconstruction, performed either — acutely, using free bone grafting or vascularized bone transfer (Figure 18 b), or — gradually, through techniques such as fibular tibialization or bone transport (Figure 18 c).

2. Staged “downgrading” of defect severity, in which acute shortening restores fragment contact and converts a C3 defect into Type C1 (defect-shortening).

After union is achieved at the contact site, the condition may subsequently be regarded as shortening requiring gradual correction (Type A2, anticipated bone defect), followed by delayed limb lengthening (Figure 18 d). This staged strategy is particularly justified in the presence of a high risk of infection or compromised soft-tissue conditions [12].

A distinct clinical scenario arises when acute shortening alone is insufficient to achieve soft-tissue closure, necessitating the creation of an intentional (“artificial”) angular deformity [16, 17]. Figure 19 illustrates a patient with a bone defect (BD) of the left tibia (4T2) associated with osteomyelitis. The proximal and distal bone ends were necrotic, and preoperatively the limb demonstrated 7 cm of shortening (Figures 19 a, b). Additionally, an atrophic medial soft-tissue wound measuring  $8 \times 3$  cm with a sinus tract was present (Figure 19 c). Following resection to viable bone, the segmental defect measured 10 cm ( $10/3 \approx 3.3$  bone diameters). Accordingly, the condition was classified as a segmental defect (Type C) with diastasis (Group 3); the total defect length corresponded to 2-4 bone



**Figure 18.** Segmental defect, Type C3 (defect-diastasis) (a); acute defect reconstruction (free bone grafting, vascularized bone transfer) (b); gradual defect reconstruction (fibular tibialization, bone transport) (c); staged delayed limb lengthening (d)

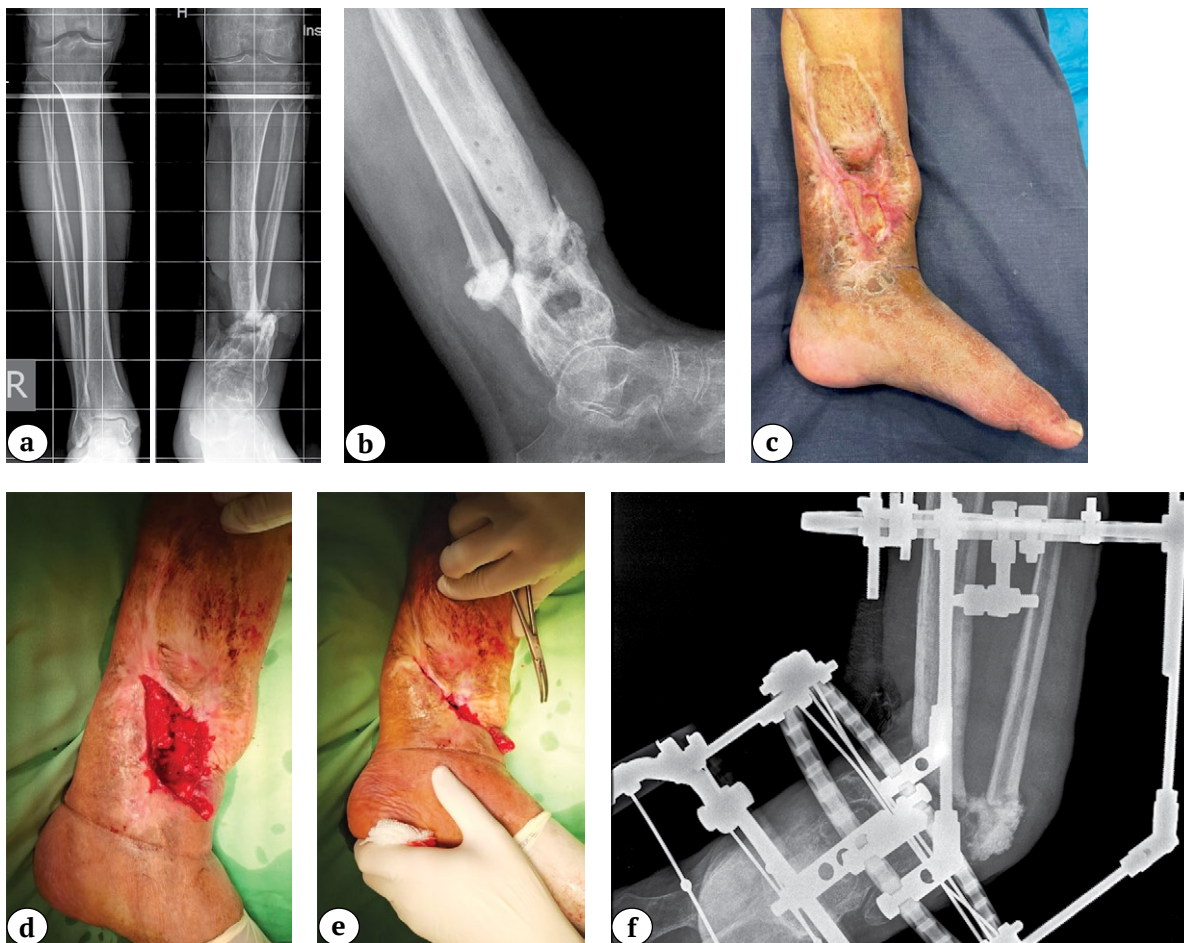
diameters (Subgroup 3), while the diastasis was  $< 1$  bone diameter (Specification 1), resulting in classification as BD 4T2 C3.3.1. Notably, although the defect was located in the periarticular region, it should be classified as segment 2 (4T2), as it represents an extra-articular segmental defect.

To facilitate soft-tissue closure, acute shortening combined with angulation was performed. This maneuver converted the defect from Type C3.3.1 (defect-diastasis) to Type C2.3.3 (defect-shortening with partial fragment contact) (Figures 19 d, e, f).

Union in this position would result in conversion of a Type C2.3 defect (Figure 20 a) into a Type A2.3 defect (anticipated bone defect: shortening + angular deformity) (Figure 20 b), rather than into Type A2.2 (isolated shortening), as would occur after simple acute shortening. In planning subsequent reconstruction, the presence of residual deformity necessitates not only proximal osteotomy for tibial lengthening,

but also an additional osteotomy at the apex of deformity in the distal third, thereby rendering the overall reconstructive strategy more complex and less favorable (Figure 20 c).

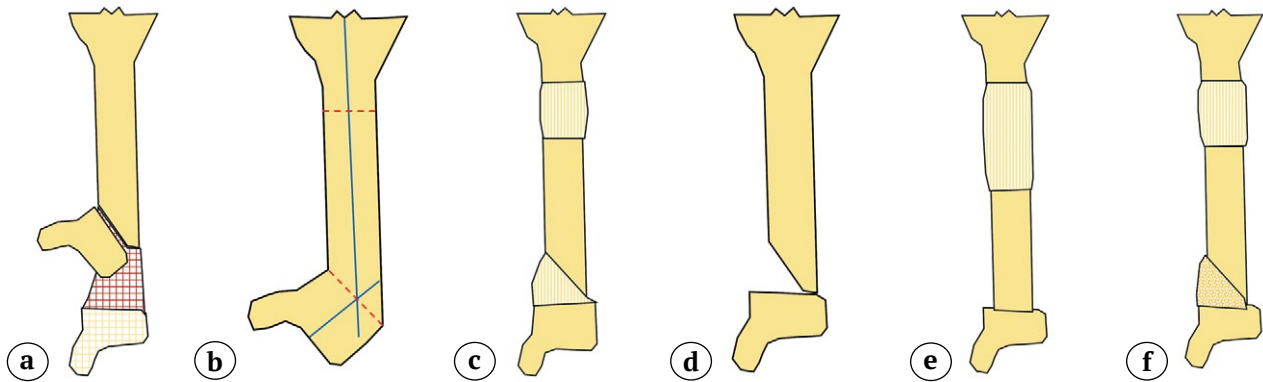
If union does not occur, the condition should continue to be regarded as a Type C2 defect-shortening with partial fragment contact (Figures 20 a, d). From a reconstructive perspective, this scenario may be conceptualized as two simpler components: 1) Type B3 defect in the distal third of the tibia, and 2) Type A2.2 (anticipated defect – shortening) in the proximal third. Management of the Type B3 component would require additional shortening with wedge resection to achieve complete fragment contact, which would further increase the total segmental defect length (Figure 20 e). Alternatively, gradual deformity correction may be performed, resulting in formation of a triangular defect with partial fragment contact requiring bone grafting (Figure 20 f).



**Figure 19.** Clinical example of a patient with a bone defect (BD) of the left tibia (4T2) and associated soft-tissue defect in the setting of osteomyelitis (explained in the text)

Provided sufficient regenerative potential, gradual correction may lead to formation of a triangular distraction regenerate. Treatment of the Type A2.2 component would necessitate

tibial lengthening in the proximal third, either simultaneously with deformity correction in the distal third or in a staged manner (Figures 20 e, f).



**Figure 20.** Possible reconstructive strategies for Type C2 defects

Thus, the ability to classify long bone defects of any localization supports the universality of the ULBDC, while the presented clinical examples highlight its practical value in guiding treatment strategy and predicting outcomes.

The principal limitation of the classification lies in its complexity, which reflects the wide spectrum of pathological conditions affecting the limb skeleton. Despite the intention to develop a comprehensive system encompassing the vast majority of long bone defects, certain rare or mixed presentations may not be fully captured. Accordingly, further refinements may be required as clinical experience with the system accumulates.

Implementation of the ULBDC in routine clinical practice may help optimize treatment strategies and improve the methodological quality of clinical research by promoting standardization, comparability, and structured documentation.

## CONCLUSIONS

The presented second edition of the Universal Long Bone Defect Classification represents a standardized, reproducible, and clinically oriented system for the description of bone defects. It is based on localization (coded according to AO/OTA principles) and defect morphology, structured within a hierarchical alphanumeric framework progressing from simple to complex. The present article addresses only the diaphyseal component of

the classification. The introduction of objective criteria, including bone integrity (Bi), defect size expressed relative to bone diameter (Bd), shortening (Sh), and diastasis (D), enables not only standardized description of clinical scenarios but also the use of the classification as an algorithmic tool for treatment selection, assessment of reconstructive complexity, and prognostic evaluation.

## DISCLAIMERS

### *Author contribution*

All authors made equal contributions to the study and the publication.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

**Funding source.** This study was not supported by any external sources of funding.

**Disclosure competing interests.** The authors declare that they have no competing interests.

**Ethics approval.** Written consent was obtained from the patients for publication of relevant medical information and all of accompanying images within the manuscript.

**Consent for publication.** Not required.

**Use of artificial intelligence.** No generative artificial intelligence technologies were used in the preparation of this manuscript.

## REFERENCES

1. Bruk B.E. Joint contractures after military trauma, their prevention and treatment. Ed. by Prof. S.N. Shilovtsev. Kuybyshev : Kuybyshev Publishing House; 1945. 82 p. (In Russian).
2. Müller M.E., Nazarian S., Koch P. The Comprehensive Classification of Fractures of Long Bones. Berlin; New York: Springer-Verlag, 1990.
3. Engh G.A., Ammeen D.J. Bone loss with revision total knee arthroplasty: Defect classification and alternatives for reconstruction. *Instr Course Lect.* 1999;48:167-175.
4. Reichel H., Hube R., Birke A., Hein W. Bone defects in revision total knee arthroplasty: classification and management. *Zentralbl Chir.* 2002;127(10):880-885. (In German). doi: 10.1055/s-2002-35134.
5. Migliorini F., La Padula G., Torsiello E., Spiezia F., Oliva F., Maffulli N. Strategies for large bone defect reconstruction after trauma, infections or tumour excision: a comprehensive review of the literature. *Eur J Med Res.* 2021;26(1):118. doi: 10.1186/s40001-021-00593-9.
6. Komarov A.V., Semenisty A.A., Sheridan G.A., Rozbruch S.R., Solomin L.N. Acquired long bone defect classifications of the diaphysis: A literature review. *J Limb Lengthen Reconstr.* 2021;7:88-97. doi: 10.4103/jllr.jllr\_27\_21.
7. Weber B.G., Oldrich C., Konstam P.G. Pseudarthrosis: Pathophysiology, biomechanics, therapy, results. New York : Grune & Stratton; 1976. 323 p.
8. Shevtsov V.I., Makushin V.D., Kufyrev L.M. Defects of lower limb bones. Kurgan: Zauralie; 1996. 502 p. (In Russian).
9. Brizhan' L., Babich M., Khominets V., Tsemko T., Artem'ev V., Aksenov Yu. The implementation of the general biological principles discovered by G.A. Ilizarov in treating the wounded and injured persons with defects of the lower limb long bone shafts. *Genij Ortopedii.* 2016;(2):21-26. (In Russian). doi: 10.18019/1028-4427-2016-2-21-26.
10. Karger C., Kishi T., Schneider L., Fitoussi F., Masquelet A.C., French Society of Orthopaedic Surgery and Traumatology (SoFCOT). Treatment of posttraumatic bone defects by the induced membrane technique. *Orthop Traumatol Surg Res.* 2012;98(1):97-102. doi: 10.1016/j.otsr.2011.11.001.
11. Solomin L., Komarov A., Semenisty A., Sheridan G.A., Rozbruch S.R. Universal long bone defect classification. *J Limb Length Reconstr.* 2022;8:54-62. doi: 10.4103/jllr.jllr\_3\_22.
12. Artemev A.A., Kerimov A.A., Nelin M.N., Grigoryev M.A., Solovev J.S., Sysoev I.A. Lower leg shortening technique in treatment of the wounded with gunshot tibial fractures. *Traumatology and Orthopedics of Russia.* 2024;30(3):12-24. (In Russian). doi: 10.17816/2311-2905-17581.
13. Bafor A., Iobst C.A. What's New in Limb Lengthening and Deformity Correction. *J Bone Joint Surg Am.* 2023;105(16):1221-1226. doi: 10.2106/JBJS.23.00310.
14. Cierny G. III, Mader J.T., Penninck J.J. A clinical staging system for adult osteomyelitis. *Contemp Orthop.* 1985;105:17-37.
15. Solomin L.N., Semenisty A.A., Komarov A.V., Khominets V.V., Sheridan G.A., Rozbruch S.R. Universal Long Bone Nonunion Classification. *Strategies Trauma Limb Reconstr.* 2023;18(3):169-173. doi: 10.5005/jp-journals-10080-1597.
16. Lerner A., Fodor L., Soudry M., Peled I.J., Herer D., Ullmann Y. Acute shortening: modular treatment modality for severe combined bone and soft tissue loss of the extremities. *J Trauma Acute Care Surg.* 2004;57(3):603-608. doi: 10.1097/01.ta.0000087888.01738.35.
17. Plotnikovs K., Kamenska J., Movcans J., Pasters V., Solomin L., Plaudis H. Artificial Deformity Creation as a Method for Limb Salvage for Patients with Massive Tibial and Soft Tissue Defects: A Report of 26 Cases. *Strategies Trauma Limb Reconstr.* 2023;18(3):133-139. doi: 10.5005/jp-journals-10080-1599.

## Authors' information

✉ Anton A. Semenisty — Cand. Sci. (Med.)  
Address: 15, Boulevard Acad. Ivan Geshov, Sofia, 1431, Bulgaria

<https://orcid.org/0000-0002-5412-6202>

eLibrary SPIN: 9574-7495

e-mail: an.semenisty@gmail.com

Leonid N. Solomin — Dr. Sci. (Med.), Professor

<https://orcid.org/0000-0003-3705-3280>

eLibrary SPIN: 1548-8722

e-mail: solomin.leonid@gmail.com

Artem V. Komarov — Cand. Sci. (Med.)

<https://orcid.org/0000-0002-8260-0311>

eLibrary SPIN: 2048-2037

e-mail: ximikatu@mail.ru