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Correction of Multiapical Deformities of Long Bones of the Lower Extremities: A Literature Review

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Abstract
Background. Multiapical deformities of the long bones of the lower extremities represent a complex and widely prevalent orthopedic pathology. A numerous of publications address its individual aspects: diagnosis, planning, and correction. However, no single study was found that offers a comprehensive assessment of contemporary views on treating patients with multiapical deformities of long bones.
Aim of the review — to define current concepts and unresolved issues in the analysis, planning, and correction of multiapical deformities of the long bones of the lower limbs based on the scientific literature.
Methods. Electronic databases were utilized for literature search: PubMed/MEDLINE, SAGE Publishing Journals, Embase, eLIBRARY, Google Scholar. Particular attention was paid to studies that provide information on diagnosis, planning, and correction methods for multiapical deformities. A total of 46 publications were included in the review.
Results. In the literature, the terms «multiapical deformity» and «multilevel deformity» are used synonymously. At the same time, the term «multilevel deformity» is used to denote uniapical deformities of different limb segments. The main diagnostic feature of a multiapical deformity is the location of the apex outside the bone. Unlike uniapical deformities, the correction planning of multiapical deformities uses the axis of the intermediate fragment(s). Most authors define it as the mid-diaphyseal line. The correction of multiapical deformities is performed either acute or gradually. Acute correction with internal fixation is undoubtedly more comfortable for the patient. If there are contraindications to it, the deformity correction is performed gradually using Ilizarov hinges or orthopedic hexapods.
Conclusions. The term «multiapical deformity» inherently indicates that the deformed bone has more than one apex, so it should take precedence over the term "multilevel deformity". The diagnostic feature of the multiapical deformity "localization of the AOD outside the bone" is not absolute and requires clarification. There are challenges in planning the correction using mechanical axes, as well as in determining the axis of the nonlinear (bowing) intermediate fragment(s). The "spring technique" has significant advantages over other variants of using orthopedic hexapods in correcting a multiapical deformity. However, a rationale for the optimal characteristics of springs, their fixation points to supports, and clarification of the computer program's use method is required. Addressing these issues will enhance the treatment efficiency for patients with multiapical deformities.

Keywords: multiapical deformities, multilevel deformities, deformity correction planning, acute deformity correction, gradual deformity correction, assisted external fixation, orthopedic hexapod, "spring techniques".

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Коррекция многовершинных деформаций длинных костей нижних конечностей: обзор литературы

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Реферат

Актуальность. Многовершинные деформации длинных костей нижних конечностей являются сложной и широко распространенной ортопедической патологией. Большое количество публикаций посвящено ее отдельным аспектам: диагностике, планированию, коррекции. Однако не было найдено ни одной работы, содержащей комплексную оценку современных взглядов на проблему лечения пациентов с многовершинными деформациями длинных костей.

Цель — основываясь на данных научной литературы, определить современные представления и нерешенные вопросы анализа, планирования и коррекции многовершинных деформаций длинных костей нижних конечностей.

Материал и методы. Для поиска литературы были использованы электронные базы данных: PubMed/MEDLINE, SAGE Publishing Journals, Embase, eLIBRARY, Google Scholar. Особое внимание уделялось работам, содержащим информацию о диагностике, планировании и методах коррекции многовершинных деформаций. В обзор было включено 46 публикаций.

Результаты. В литературе как синонимы используются термины «многовершинная деформация» и «многоуровневая деформация». Одновременно с этим термин «многоуровневая деформация» используется для обозначения одновершинных деформаций разных сегментов конечности. Основным диагностическим признаком многовершинной деформации является расположение вершины за пределами границ кости. В отличие от одновершинных деформаций, при планировании коррекции многовершинных деформаций используется ось промежуточного(-ых) фрагмента(-ов). Большинство авторов определяют ее как среднедиафизарную линию. Коррекция многовершинных деформаций выполняется одномоментно или постепенно. Одномоментная коррекция с внутренней фиксацией, несомненно, является более комфортной для пациента. При наличии противопоказаний к ней устранение деформации выполняется дозированно с использованием унифицированных репозиционных узлов или ортопедических гексаподов.

Заключение. Термин «многовершинная деформация» априори показывает, что деформированная кость имеет несколько вершин деформаций, поэтому он должен иметь приоритет перед термином «многоуровневая деформация». Диагностический признак многовершинной деформации «локализация вершины деформации за пределами границ кости» не является абсолютным и требует уточнения. При планировании коррекции имеются сложности при использовании механических осей, а также определения оси нелинейного промежуточного фрагмента (фрагментов). «Пружинная техника» имеет значимые преимущества перед другими вариантами применения ортопедических гексаподов при коррекции многовершинной деформации. Однако необходимо обоснование оптимальных характеристик эластичных тяг, точек их фиксации к опорам, а также уточнение способа использования компьютерной программы. Решение данных задач позволит повысить эффективность лечения пациентов с многовершинными деформациями.

Ключевые слова: многовершинные деформации, многоуровневые деформации, одномоментная коррекция деформаций, постепенная коррекция деформаций, ассистирующая внешняя фиксация, чрескостный остеосинтез, ортопедический гексапод, «пружинная техника».

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BACKGROUND

The definitions of the term "deformity" from a technical and orthopedic point of view differ significantly. From a technical standpoint, deformation is a change in the relative positions of points of a solid body, the distance between which changes under the influence of external forces*. In orthopedic surgery, the concept of "deformation" implies a discrepancy of reference lines and angles from accepted norm values in the presence or absence of shortening [1, 2, 3]. Components of deformation include displacement along the length, angular displacement, peripheral displacement, and rotational displacement. In the presence of angular deformity, the term "apex of deformity – AOD" is used – the point of intersection of the axes of the proximal and distal parts of the bone [2, 4, 5, 6, 7, 8]. The terms "Center of Rotation of Angulation - CORA" [9, 10, 11, 12, 13, 14], "Center of deformity – CD" [15] and "Vertex" [16] are used in a similar meaning.

Deformities can have one or multiple apexes. Deformation with multiple apexes within one segment is referred to as multiapical deformity [3, 6, 13, 17, 18] or multilevel deformity [5, 7, 8, 19, 20, 21]. Multiapical deformities (MD) of the long bones in the lower extremities are relatively common and complex orthopedic pathologies that lead to severe disruptions in the statics and kinetics of the musculoskeletal system [5, 21, 22]. Specialized publications have addressed specific aspects of MD, including diagnosis, planning, and correction, particularly concerning different segments. However, no comprehensive review has been found that provides a holistic assessment of contemporary perspectives on the treatment of patients with MD of long bones.

Aim of the review – to define current concepts and unresolved issues in the analysis, planning, and correction of multiapex deformities of the long bones of the lower limbs based on the scientific literature.

METHODS

A literature search was conducted in the following electronic databases: PubMed/MEDLINE, SAGE Publishing Journals, Embase (in English), eLIBRARY (in Russian), Google Scholar (in Russian and English). The following keywords were used: multiapical deformities, multilevel deformities, acute deformity correction, gradual deformity correction, acute deformity correction, assisted external fixation, Ilizarov apparatus, orthopedic hexapods, spring technique. Key terms in Russian and English were used to ensure comprehensive coverage.

Inclusion criteria:

1) studies of all levels of evidence;
2) publications containing information about the treatment of patients with MD of long bones in the lower extremities;
3) publications that define the term "deformation" and contain data on the diagnosis, planning, and treatment of long bone deformities;
4) availability of the full text of the publication in Russian or English.

The review included 47 publications (8 in Russian and 39 in English). Particular attention was given to the methods used by authors to correct MD, indicators of accuracy and duration of correction, as well as complications.

It should be noted that the vast majority of reviewed sources consisted of expert opinions [1, 11, 19, 23, 24, 25], case analysis or series of clinical cases [4, 11, 17, 18, 20-37]. Many authors did not distinguish patients with MD as a separate group in their studies, making it difficult to interpret the results within the scope of the topic [4, 11, 18, 29, 35, 37, 38]. Based on this, it can be concluded that there is a deficiency in high-evidence research in this area.

RESULTS

As previously noted, in scientific literature, two terms, multiapical deformity and multilevel deformity, are used synonymously to denote deformations with multiple apices within one segment. Simultaneously, the term "multilevel deformity" is used to refer to uniapical deformities of different segments within one limb [39].

The diagnosis of multiapical deformities of the femur or tibia is discussed in 12 publications [1, 6, 8, 9, 12, 13, 17, 21, 24, 29, 34, 35]. In these publications, the primary criterion for MD is the localization of the deformity apex outside the bone: medially, laterally, anteriorly, or posteriorly (Fig. 1a), as well as higher or lower (Fig. 1b). Diagnosis of MD of the tibia is recommended to be performed using mechanical axes, while the femur is recommended to use anatomical axes [1, 12]. Other diagnostic criteria for MD mentioned in the literature include:

– the presence of a "bowing" bone [8] (Fig. 1 c);

– deviation of one of the angles from reference values when crossing anatomical axes in the area of "obvious deformity" [8] (Fig. 1 d);

– the localization of the deformity apex within the bone but outside the obvious deformity" [1, 8] (Fig.1 e);

– the presence of parallel axes in the proximal and distal segments of the bone [8] (Fig. 1 f).

Planning for the correction of multiapical deformities is discussed in 12 studies [1, 6, 8, 9, 12, 13, 17, 21, 24, 29, 34, 35]. In addition to the axes of the proximal and distal segments of the bone, the axis of the intermediate part of the bone where osteotomies will be performed to create intermediate fragments is also used.

The majority of authors agree that the axis of the intermediate fragment is the mid-diaphyseal line [8, 12, 13, 17, 21, 29, 34]. However, in D. Paley's study, an alternative position is presented, suggesting that the axis of the intermediate fragment "can be drawn at different orientations" [9] (Fig. 2). Based on the illustration provided in his article, it can be assumed that any position and angle of inclination of the axis of the intermediate segment are permissible as long as it intersects with the axes of the proximal and distal segments of the bone and does not extend beyond the bone's boundaries.

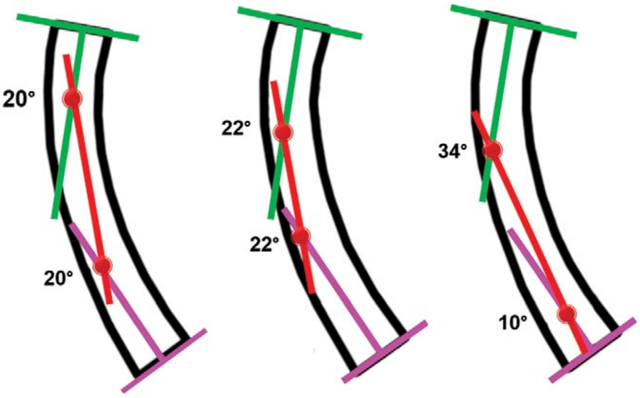

Fig. 2. Different options of identifying the axis of intermediate fragment according to D. Paley [9]

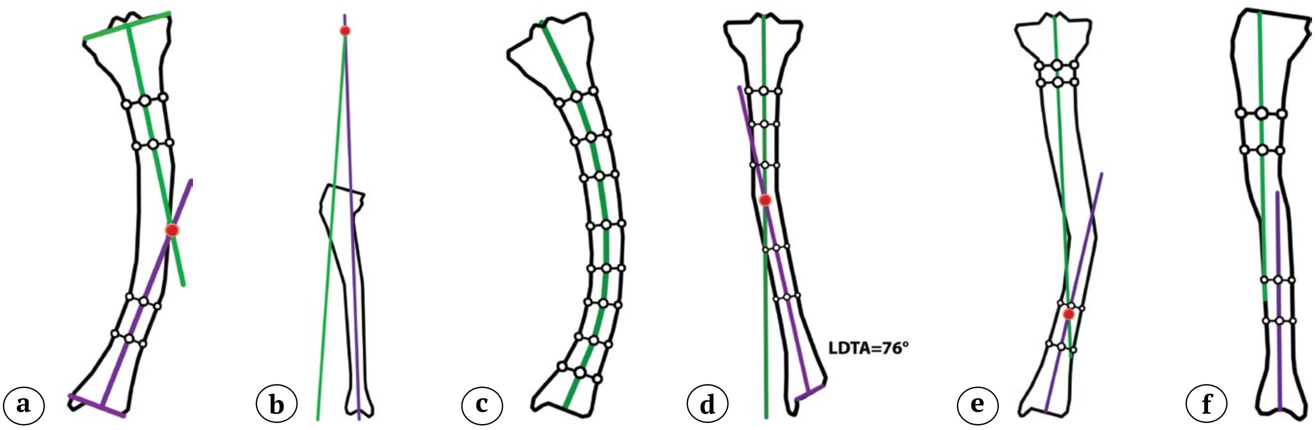

Fig. 1. Diagnostic signs of MD (using the tibia as an example):
a — AOD is located outside of the bone (laterally);
b — AOD is located outside of the bone (proximally);
c — the bone has a long, curving bow;
d — the bone segment has an obvious deformity plus the LDTA formed by the mid-diaphyseal line is abnormal;
e — AOD doesn't match the obvious deformity;
f — the proximal and distal axes are parallel

Authors concur that the points of intersection of the axis of the intermediate segment with the axes of the proximal and distal segments are optimal for performing osteotomies. Correction at each apex is carried out according to the 1st osteotomy rule. In cases where the size of one of the segments is too small, the use of the 2nd osteotomy rule is recommended [8]. If correction of deformities with more than two apexes is required [4, 17, 20, 30, 31, 35, 37], planning is carried out using axes of multiple intermediate fragments [1, 20]. In planning the correction of tibia deformities, D. Paley recommends the following algorithm [1]:

1) draw mid-diaphyseal lines of the proximal and distal segments of the bone;

2) determine the correspondence of anatomical angles to normative values; in case of mismatch, draw anatomical axes corresponding to the norm;

3) identify AODs (points of intersection of the axes of the proximal, intermediate, and distal fragments), measure the angular deformities for each AOD, and determine the optimal levels for performing osteotomies.

Correction of deformities, including multiapical ones, can be performed either acutely or gradually, i.e. progressive. The following advantages of acute correction with internal fixation over gradual correction have been identified:

1) convenience for the patient due to the absence of bulky external metal constructs [17, 18, 24, 29, 30];

2) prevention of deformity recurrence and refractures, especially in cases of osteogenesis imperfecta [17, 28];

3) absence of complications typical of external fixation, such as transfixation contractures and inflammations around the transosseous elements [30, 31];

4) elimination of the need for patient and/or orthopedic curator participation in the correction process [40];

5) reduction of overall treatment duration [29].

The use of monolateral [17, 24] or circular [31] frames as assisted external fixation increases the accuracy of acute correction [18, 24, 27, 29, 31]. This method has been successfully applied in the correction of multiapical deformities of the long bones in the lower extremities. For the final fixation of bone fragments during single-step correction of multiapical deformities, intramedullary nails were used (Table 1).

At acute correction, according to various authors, the total magnitude of angular deformity should not exceed 20-35° [4, 10, 41, 42], and torsional deformity should not exceed 20° [41]. Acute correction with internal fixation compared to gradual correction has the following disadvantages:

– longer duration of the operation [38];
– lower accuracy of correction [7, 29];
– inability to correct residual deformity [7, 29];
– longer time required for consolidation [10, 44];
– risk of deep infection [17, 28, 29, 31];
– greater intraoperative blood loss [38];
– objective limitations on the magnitude of deformity that can be corrected without the risk of neurotrophic complications [10, 29, 38, 41, 42].

In cases where there are contraindications to acute correction, gradual correction should be used. This method is preferable when there is a need to correct complex (multi-planar, multi-component) deformities [1, 7, 44]. Ilizarov hinges [4, 28, 32, 33] and orthopedic hexapods [11, 20, 21, 34, 35, 36, 37] were used in gradual correction of MD (Table 2).

Orthopedic hexapods offer several advantages over Ilizarov hinges:

– the ability to correct all components of the deformity in a one-step procedure [2, 11, 20, 44];
– better accuracy of correction, especially when dealing with complex deformities [11, 40, 44, 45, 46];
– a shorter learning curve [34, 40, 44, 45].

As of today, there are three techniques for correcting MD using orthopedic hexapods:

1) simultaneous correction of multiple apexes of the deformity using multiple orthopedic hexapods, one at each apex [11, 14, 21, 25, 34, 36, 37, 47];

2) sequential correction of MD using a single hexapod [21]. When correcting at the level of one apex, the level of the other(s) is fixed. Deformity is corrected sequentially at each apex;

3) simultaneous correction of multiple apexes of the deformity using a single orthopedic hexapod with the use of the so-called "spring technique" [19]. The struts of the orthopedic hexapod are fixed to proximal and distal rings. An intermediate ring (one or more) is fixed to adjacent supports using elastic springs. When correction is performed, the intermediate fragment "automa-tically" takes its correct position.

Despite all the positive qualities, orthopedic hexapods have a significant disadvantage - relatively high cost, making them less accessible for widespread use compared to the Ilizarov apparatus [33, 34].

Table 1

Studies on acute correction of multiapical deformities (level of reliability higher than expert opinion)

Author, publication year	Methodology	Number of patients (segments)	Correction accuracy	Consolidation period	Complications
Bilen F.E. et al., 2010 [17]	Fixator-assisted nailing	4 (4)	MAD +2.25 mm (0–6) MPTA 89.75° (89–90) LDTA 90° (90)	Average BHI — 43 days/cm (30–48))	1st degree by Caton — 2 episodes
Galal S., 2017 [18]	Fixator-assisted nailing	≥1(≥1)	N/a	N/a	N/a
Paley D. et al., 1997 [26]	Fixator-assisted nailing	n/a (8)	±1° from planned	N/a	Absent
Eralp L. et al., 2004 [27]	Fixator-assisted nailing (FAN)	2 (7)	MAD +8.75 mm (5–11) MPTA 86.5° (85–90) LDFA 87.5° (86–90)	N/a	Absent
Song H.R. et al., 2006 [28]	Final locking nail fixation	≥1(≥1)	N/a	N/a	N/a
Eralp L. et al., 2011 [29]	Fixator-assisted nailing	≥1(≥1)	N/a	N/a	N/a
Kocaoğlu M. et al., 2011 [30]	Fixator-assisted nailing	17 (43)	LDFA 87° (80–92) (val.), 90° (87–109) (var.); MPTA 88° (86–90) (var.), 87° (85–91) (val.); MAD (var.) +7 мм (0–29); MAD (val.) -6 (-20…+7)	N/a	1st degree by Caton — 5 episodes, 2nd degree by Caton — 4 episodes
Hughes A. et al., 2017 [31]	Fixator-assisted internal fixation	N/a (12)	N/a	N/a	N/a
Chaudhary M.M. et al., 2019 [38]	Fixator-assisted nailing	12 (12)	LDFA 89.1° (80.4–90.0) PDFA 86.6° (82.0–90.3) MAD restored in 42% of cases	161 days (103–208)	N/a

MAD — mechanical axis deviation; LPFA — lateral proximal femoral angle; PDFA — posterior distal femoral angle; LDFA — lateral distal femoral angle; MPTA — medial proximal tibial angle; LDTA — lateral distal tibial angle; BHI — bone healing index; N/a — not available; val. — valgus; var. — varus.

Table 2

Studies on gradual correction of multiapical deformities (level of reliability higher than expert opinion)

Author, publication year	Methodology	Number of patients (segments)	Correction accuracy	Correction and fixation period	Complications
Zyrjanov S.Y., 1995 [4]	Use of Ilizarov hinges	<66 (N/a)	N/a	N/a	N/a
Ganger R. et al., 2009 [11]	Simultaneous correction using multiple Hexapods	≥1 (≥1)	N/a	N/a	N/a
Solomin L.N. et al., 2017 [20]	«Spring technique»	7 (7)	97.6%	6 (4–9) weeks; 47 (37–54) weeks	1st degree by Caton — 2 episodes, 2nd degree by Caton — 1 episode
Vilenskiy V.A. et al., 2019 [21]	Simultaneous correction using multiple Hexapods	25 (30)	Val: MPTA 90.1±4.4° LDTA 86.5±8.0° Var: MPTA 88.6±1.8° LDTA 88.7±4.4°	31.1±20 days; 47 (37–54) weeks.	1st degree by Caton — n/a ("almost in all"), 2nd degree by Caton — 11 cases
	Gradual deformity correction using one Hexapod	14 (19)	Val: MPTA 90.9±2.3° LDTA 89.7±5.5° Var: MPTA 87±3.2° LDTA 86±11.2°	27.1±48.3 days; 177.8±10.3 days	1st degree by Caton — more than 3 episodes ("almost in all"), 2nd degree by Caton — 5 episodes (26%)
Song H.R. et al., 2006 [28]	Use of Ilizarov hinges	≥1(≥1)	N/a	N/a	N/a
Vaidya S.V., 2006 [32]	Use of Ilizarov hinges	24 (47)	MPTA 86.3±6.4° LDTA 91.2±8.4° MAD 4.7±11.6 мм	n/a; Average BHI 26.06±3.27 days/cm	1st degree by Caton — 17 episodes; 2nd degree by Caton — 29 episodes
Matsubara H. et al., 2008 [33]	Use of Ilizarov hinges	2 (6)	LDFA 88° (87–90); MPTA 86.5° (85–88); LDTA 87° (86–88)	n/a; 146 (133–157) days	Absent
Naqui S.Z.H. et al., 2008 [34]	Simultaneous correction using multiple Hexapods	≥1 (≥1)	N/a	N/a	N/a
Koren L. et al., 2016 [35]	Simultaneous correction using multiple Hexapods	≥2 (≥2)	N/a	N/a	N/a
Riganti S. et al., 2018 [36]	Simultaneous correction using multiple Hexapods	≥1 (≥1)	N/a	N/a	N/a

MAD — mechanical axis deviation; LPFA — lateral proximal femoral angle; PDFA — posterior distal femoral angle; LDFA — lateral distal femoral angle; MPTA — medial proximal tibial angle; LDTA — lateral distal tibial angle; BHI — bone healing index; N/a — not available; val. — valgus; var. — varus.

DISCUSSION

There is terminological confusion arising from the use of "multiapical deformity" and "multilevel deformity" as synonyms. In our opinion, the term "multiapical deformity" inherently indicates that the deformed bone has several (two or more) apexes of deformity. Therefore, we consider that preference should be given to this term. The term "multilevel deformity" is more appropriate for denoting deformities in different segments of the same limb.

The diagnosis of MD (multiapical deformity) deserves separate consideration. Signs referred to as "bow curving bone "and"deviation of one of the angles from the reference values when crossing anatomical axes in the area of "obvious deformity" are illustrated in Fig. 1 c and 1 d. However, when determining the MD using mechanical axes in both cases, the point of intersection is located outside the bone (Fig. 3 a, b). Thus, the discussed signs are not independent but rather specific cases of feature No. 1, which is "location of the MD outside the boundaries of the bone."

Another MD feature, "localization of the apex of deformity outside the obvious deformity," (see Fig. 1e) also cannot be considered universal. With standard planning using mechanical axes, the MD is determined within the boundaries of the bone, allowing correction according to the 1st osteotomy rule (Fig. 3 c).

Deformity with parallel axes of the proximal and distal fragments (Fig. 1 f) is referred to in the literature as "isolated translation deformity." Its correction can be performed with either one or two osteotomies. The question of whether translational deformities corrected with two osteotomies can be classified as multiapical is a subject of debate.

Despite the fact that restoring proper relationships between reference lines and angles is a key goal of deformity correction, the bone's shape after correction must also be taken into account. MD correction can be successfully accomplished with a single osteotomy, following either the 1st osteotomy rule (for MD located anteriorly, posteriorly, medially, or laterally to the bone's boundaries) or the 2nd osteotomy rule (for MD located above or below the bone). However, in the first case, a "zig-zag" in the anatomical axis and a bony "bump" may occur [6], while in the second case, pronounced distal fragment translation occurs. Performing multiple osteotomies can eliminate these undesirable outcomes. The optimal number of osteotomies in specific cases and the best levels for their execution remain points of discussion.

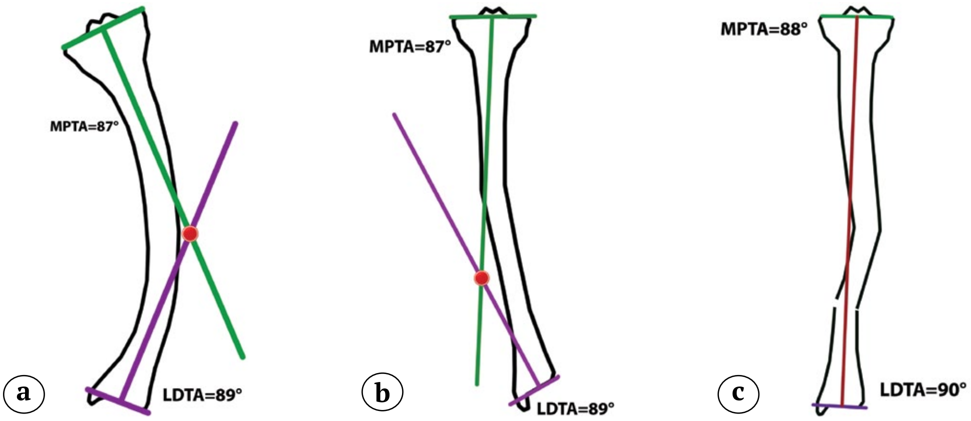

Fig. 3. Analysis of the diagnostic signs of MD:
a — correction planning using the mechanical axes of the proximal and distal bone fragments (analysis of sign N 2);
b — correction planning using the mechanical axes of the proximal and distal bone fragments (analysis of sign N 3);
c — correction according to the 1st osteotomy rule (analysis of sign N 4)

In the implementation of most MD correction techniques, the axis of the intermediate fragment is aligned with the proximal fragment's axis, and the axis of the distal fragment is aligned with the intermediate fragment's axis. However, this method can be easily implemented only when the intermediate fragment's axis is linear (i.e., straight). If we consider the axis of the intermediate fragment as the mid-diaphyseal line, then in cases where the intermediate fragment (and thus its axis) is nonlinear, the realization of the described method becomes impossible. Recommendations for planning MD correction, as described by D. Paley et al. (See Fig. 2) and the algorithm for planning three apical deformities, become significantly more challenging when dealing with nonlinear fragments. The more "curved" the bone is, the more challenging it is to implement the described planning method; there are no recommendations on how many straight segments the anatomical axis curve should be divided into.

Diagnosing deformity and preoperative planning are just the initial steps in the treatment of patients with MD. A literature analysis has shown that the most common surgical treatment methods for MD at present are acute correction with internal fixation using intramedullary rods and gradual correction using orthopedic hexapods.

One of the most important indicators in assessing correction results is its accuracy. However, only 10 out of 20 authors provided these data. Furthermore, in some studies, correction accuracy is reflected as percentages [20], while in others, values of reference lines and angles are provided [17, 21, 26, 27, 30, 32, 33, 37, 38]. All of this creates challenges for an objective evaluation of the effectiveness of the methods being used.

As previously noted, despite its advantages, acute correction with internal fixation has objective limitations and contraindications. In cases where these exist, gradual correction is preferable. However, techniques for gradual correction using orthopedic hexapods also have their disadvantages. When multiple hexapods are used simultaneously, the construct becomes excessively heavy and cumbersome, increasing patient discomfort associated with the external fixation frame. There is also an increase in labor requirements; the orthopedic surgeon must perform several isolated calculations in the computer program, and during correction, adjustments need to be made not for just six, but for twelve, or in the case of threeapical deformities, eighteen struts. Additionally, the economic burden on the healthcare facility increases because more orthopedic hexapods are required to implement this method.

In sequential correction using a single hexapod, a choice must be made regarding which apex to start correction from, and two separate calculations are necessary. The correction period increases proportionally with the number of deformity apexes (See Table 2). Premature consolidation at the level of the apex «awaiting» correction is possible.

The "spring technique" aims to overcome the drawbacks of both methods. This technique involves using only one hexapod, which is more comfortable for both the surgeon and the patient. The correction is performed simultaneously at multiple apexes, reducing its duration. However, despite the promise of this technique, several technical details essential for its successful realization remain unclear:

– the optimal number and technical characteristics of elastic rods;

– the optimal points for attaching elastic rods to supports;

– the specifics of using computer software for orthopedic hexapods when the "spring technique" is realized.

In the "spring technique," during the calculation of correction in the computer program, the distal fragment's axis is aligned with the proximal fragment's axis, ignoring the intermediate fragment's axis. In this case, it remains unclear how to define the "yellow contour" in the computer program, indicating the initial position of the mobile bone fragment: should it correspond to the boundaries of the distal fragment or include the intermediate fragment entirely or partially? Another function of the "yellow contour" is to establish so-called "structures at risk" (SAR) based on its boundaries. SAR are critical points for calculating the number of correction days in the program. SAR represent the point at the proximal edge of the distal fragment that will undergo the greatest displacement in both the frontal and sagittal planes during correction.

In the implementation of the "spring technique," the first stage of correction (distraction) is performed using the orthopedic hexapod at one apex and two-plane Ilizarov hinges at another apex. When performing the standard calculation in the computer program to achieve distraction, axes of the proximal and distal (mobile) fragments are required. Based on this, the algorithm built into the program aligns the distal fragment's axis with the proximal one. Therefore, in cases where one axis is not an extension of the other, meaning there is angular deformity, the distal fragment will experience displacement in width and/or at an angle (Fig.4).

The "free movement" of the red contour using program options is not technically sound and may cause a malfunction in the program. Therefore, the technique for correctly performing distraction using an orthopedic hexapod when implementing the "spring technique" currently requires clarification.

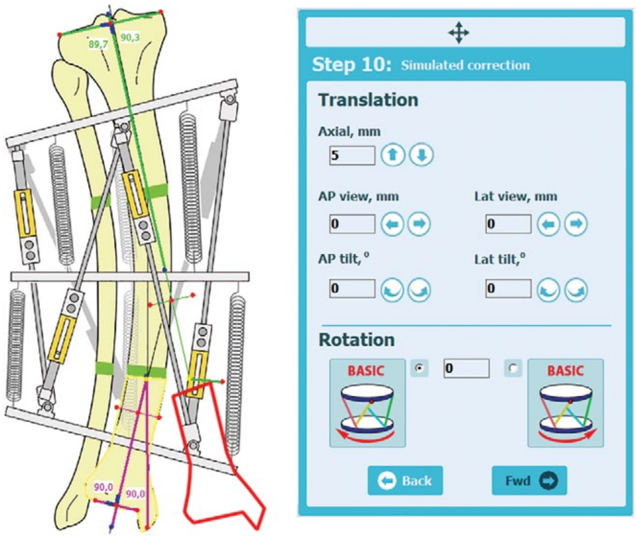

Fig. 4. When trying to identify the axes of the proximal and distal fragments by the standard method, the program calculates not the plane-parallel distraction, but the translation and angulation of the distal fragment

CONCLUSIONS

The term "multiapical deformation," in contrast to the term "multilevel deformation," inherently indicates the presence of two or more deformation apexes in the bone. Therefore, it should be used to denote this pathology. The key diagnostic feature of MD is the localization of the point of intersection of the axes of the proximal and distal fragments outside the bone. However, it is not an absolute feature and requires further clarification. Unlike uniapical deformities, MD requires the use of intermediate fragment(s) axes for planning correction. To date, there is no known method for accurately determining the axis of a nonlinear intermediate fragment(s). It remains unknown how to perform MD correction planning based on mechanical axes.

Acute correction of MD with intramedullary fixation and gradual correction using several orthopedic hexapods (one for each deformity apex) are the most commonly used methods. The "spring technique" has clear advantages as it allows the use of only one orthopedic hexapod and one calculation for MD correction. However, there is a need for justification of the optimal characteristics of elastic rods, their fixation points, and clarification of the method for using the hexapod's computer program, specifically for calculating initial distraction and defining the boundaries of the movable fragment and "structures at risk." Addressing these challenges will enhance the effectiveness of treating patients with MD of the long bones of the lower extremities.

DISCLAIMERS

Author contribution

Evgeniy S. Golovenkin — literature search and review, drafting the manuscript.

Leonid N. Solomin — study concept and design, data analysis and interpretation, editing the manuscript.

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.

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