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Classification of Midfoot Deformities in Charcot Neuroarthropathy

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Abstract

Background. Midfoot pathology accounts for 60-70% of all deformities in diabetic Charcot neuroarthropathy. However, the available classifications of this pathology are few and have certain disadvantages.

The aim of the study — to analyze X-rays of patients to investigate the displacement patterns of the midfoot bone and joint structures in Charcot neuroarthropathy, and, based on the identified displacement trends, to develop an anatomical and radiological classification of midfoot deformities.

Methods. A retrospective analysis was performed on the foot X-rays of 416 patients (436 feet) with midfoot pathology in Charcot neuroarthropathy. Of these, 233 X-rays were provided by inpatient hospitals, and 203 – on an outpatient basis. Only X-rays taken in anteroposterior and lateral views were included in the analysis. We assessed the alignment of bones within the foot joints, the extent of destruction, and the direction of the displacement of bony structures.

Results. The following types of lesions are identified. 1A — involvement of the navicular bone and talar head with the preservation of the lateral column anatomy. 1B — simultaneous involvement of the talonavicular and calcaneocuboid joints. 1C — subluxation or dislocation at the talonavicular joint with transition to the lateral parts of the tarsometatarsal joint with plantar dislocation of the cuboid bone and preservation of anatomical integrity in the calcaneocuboid joint. 1D — complete displacement of the navicular bone with the dislocation at the talonavicular, naviculocuneiform and tarsometatarsal joints. 2 — deformation (subluxation, dislocation, fracture-dislocation) of the naviculocuneiform joint, with involvement of the lateral column at the metatarsocuboid joint and flattening of the medial column. 3 — isolated involvement of the Lisfranc joint. 4A — isolated involvement (subluxation or dislocation) of the first cuneometatarsal joint without visible deformity in the affected area. 4B — dislocation at the medial naviculocuneiform and medial cuneometatarsal joints with the displacement of the medial cuneiform bone relative to the other foot bones. 5 — varus deformity of the foot with fractures of the metatarsal bones.

Conclusion. A new classification of Charcot midfoot lesions is intended to guide the selection of key reconstructive surgical interventions for this pathology.

Keywords: neuroarthropathy; Charcot foot; diabetic foot; midfoot; deformity; classification.

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Классификация деформаций среднего отдела стопы при остеоартропатии Шарко

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Реферат

Актуальность. Поражения среднего отдела стопы составляют 60–70% от всех деформаций при диабетической нейроостеоартропатии Шарко, однако имеющиеся классификации этой патологии немногочисленны и имеют недостатки.

Цель исследования — на основании анализа рентгенограмм изучить характер смещения костно-суставного аппарата среднего отдела стопы при остеоартропатии Шарко и с учетом закономерностей смещения разработать анатомо-рентгенологическую классификацию деформаций среднего отдела стопы.

Материал и методы. Проведен ретроспективный анализ рентгенограмм 416 пациентов (436 стоп) с патологией среднего отдела как проявлением нейроостеоартропатии Шарко. Из них 233 рентгенограммы были выполнены в стационарах, а 203 — амбулаторно. Для анализа отбирались рентгенограммы в прямой и боковой проекциях. Оценивали соотношение в суставах стопы, объем деструкций, направление смещения костей.

Результаты. Выделены следующие варианты поражения. 1А — поражение ладьевидной кости и головки таранной кости с сохранением анатомии латеральной колонны. 1Б — одновременное поражение таранно-ладьевидного и пяточно-кубовидного суставов. 1В — подвывих или вывих в таранно-ладьевидном суставе с переходом на латеральные отделы предплюсне-плюсневого сустава с дислокацией кубовидной кости плантарно и сохранением анатомической целостности в пяточно-кубовидном суставе. 1Г — тотальное смещение ладьевидной кости с вывихом в таранно-ладьевидном, ладьевидно-клиновидных и предплюсне-плюсневом суставах. 2 — деформация (подвывих, вывих, переломо-вывих) на уровне ладьевидно-клиновидного сустава с поражением латеральной колонны в кубовидно-плюсневом суставе и уплощением медиальной колонны. 3 — изолированное поражение сустава Лисфранка. 4А — изолированное поражение (подвывих или вывих) первого плюсне-клиновидного сустава при отсутствии видимой деформации в зоне поражения. 4Б — вывих в медиальном ладьевидно-клиновидном и медиальном плюсне-клиновидном суставе со смещением медиальной клиновидной кости относительно остальных костей стопы. 5 — варусная деформация стопы с переломом плюсневых костей.

Заключение. Новая классификация поражений среднего отдела предназначена для определения ключевых направлений реконструктивных оперативных вмешательств при данной патологии.

Ключевые слова: нейроостеоартропатия; стопа Шарко; диабетическая стопа; средний отдел; деформация; классификация.

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INTRODUCTION

Diabetes mellitus is one of the most widespread non-infectious diseases, with an annual growth rate that has reached epidemic proportions. According to the International Diabetes Federation (IDF), as of 2021, 537 million people worldwide were diagnosed with *diabetes mellitus*, and this number is projected to increase to 783.2 million by 2045 [1]. Along with the rising prevalence of diabetes, the number of its complications is also increasing, affecting various organs and systems. One such complication is Charcot neuroarthropathy (CN), also known as Charcot foot. Its prevalence ranges from 0.56% in primary care facilities to 10-12% in specialized medical centers [2]. CN is a non-infectious arthropathy that affects the bones and joints of the foot and ankle, leading to destruction and disturbance of the bone and joint architecture of the foot [3].

The most common localization of CN is the midfoot, which is affected in 50-70% of cases. Among these, the involvement of the tarsometatarsal joints accounts for approximately 40%, while damage to the naviculocuneiform, talonavicular, and calcaneocuboid joints occurs in 30% of cases. Furthermore, it has been noted that plantar ulceration most often develops in conjunction with midfoot deformities [4, 5, 6, 7].

As CN progresses and axial loading on the foot continues, significant deformities can develop, potentially compromising the weight-bearing function of the limb. Conservative treatment, which includes offloading and immobilization of the affected extremity, does not always succeed in halting further progression of the deformity. In addition, according to the latest systematic review, CN is diagnosed late in 53.2% of cases, with an average diagnostic delay of 86.9 days. As a result, patients often seek medical care at a stage when severe deformities have already developed, rendering conservative management ineffective and substantially increasing the risk of ulceration and limb amputation [5, 8, 9]. It is evident that the treatment strategy should be primarily guided by the nature of the foot deformities. This highlights the need for a practically oriented classification of midfoot lesions in Charcot neuroarthropathy.

The development of CN classifications began abroad in 1966, and to date, there are nine systems, thoroughly reviewed by V.B. Bregovskiy et al. [10]. Most of these classifications stratify the types of deformities and bone destruction in one way or another, but they are not directly linked to surgical management strategies. Only two of them associate certain types of lesions with an overall poor prognosis for the limb, both in general and after foot reconstruction surgery: types 3 and 4 in the classification by L.J. Sanders and R.G. Frykberg, and lesions of the talocalcaneal joint and varus foot deformities in the classification by M. Pinzur and A. Schiff [4, 11].

In Russian-language literature, two research groups have addressed the issue of CN classification. In the work by V.N. Obolensky et al., a combined approach was proposed for assessing the condition of the foot. It included the Sanders and Frykberg classification of CN, the Eichenholtz radiographic staging, Wagner's ulcer classification, and a typology of foot deformities (valgus, varus, equinus, and rocker-bottom deformities) [12, 13]. Based on this system, the authors developed a rationale for the surgical treatment of CN complicated by septic and necrotic processes. However, a disadvantage of this classification is its complexity, as well as the fact that the possible deformities of the midfoot are not limited to the variants presented. These deformities are often more complex and multiplanar in nature.

The second Russian classification of foot deformities in diabetic foot syndrome was published by M.V. Parshikov et al. [14]. They proposed that within a comprehensive classification of secondary deformities, hindfoot and midfoot lesions in CN should be considered separately. According to their concept, hindfoot pathology is divided into three degrees based on the angle of calcaneal tuberosity deviation, while midfoot pathology is also categorized into three degrees depending on the presence of a prominent bone fragment or the formation of a rocker-bottom deformity. Like previous international classifications, this classification is descriptive and does not provide a framework for tailoring orthopedic reconstruction procedures to individual patients.

Our analysis of the literature has revealed several common disadvantages across existing classifications. First, there is a biased sampling (patients of septic and orthopedic departments).

It is evident that patients admitted to hospitals usually have more severe deformities, which are the logical progression of milder deformities observed in outpatient settings. Studying outpatient cases would allow for a broader understanding of the full spectrum of pathology and help trace the progression patterns of deformities — factors that could be critical in choosing appropriate orthopedic fixation methods and surgical strategies. Second, the number of examined patients or X-rays in these studies is often small. Combined with biased sampling, this limitation leads to the underestimation of the incidence of various deformity types and increases the likelihood of overlooking rare variants. Third, none of the existing classifications consider the mechanisms behind the development of specific foot deformities, such as the role of external forces or the actions of muscles and tendons in shaping deformity patterns. Finally, all published classifications are primarily descriptive and not integrated with treatment decision-making in orthopedic surgery.

The aim of the study — to analyze X-rays of patients to investigate the displacement patterns of the midfoot bone and joint structures in Charcot neuroarthropathy, and, based on the identified displacement trends, to develop an anatomical and radiological classification of midfoot deformities.

METHODS

Study design

Study design: multicenter retrospective.

A retrospective analysis was performed on the foot X-rays of patients with diabetic CN affecting the midfoot (or both feet in cases of bilateral arthropathy).

Patients who had previously undergone minor amputations or reconstructive procedures on the foot bones were not included in the study, as such interventions alter the biomechanics of the foot and affect the pattern of deformity progression.

Since the study focused solely on radiographic findings, the evaluation of the initial X-rays did not take into account patient characteristics such as diabetes type and duration, sex, age, or the state of arterial blood flow. Likewise, the integrity of the skin, the presence of ulcerative lesions, or deep infection associated with previously developed deformities were not considered.

Only X-rays taken in anteroposterior and lateral views were included in the analysis. Weight-bearing X-rays were excluded, as although they may demonstrate deformity under load and highlight pressure points, they do not provide additional information regarding the positioning of already dislocated bones. We assessed the alignment of bones within the foot joints, the extent of destruction, and the direction of the displacement of bony structures. The analysis of deformities was carried out with consideration of the functional anatomy of the foot and the displacement vectors of bony elements during unprotected roll-over under the influence of muscular and ligamentous forces [15].

A total of 233 X-rays were provided by inpatient hospitals: the Foot and Diabetic Foot Surgery Center of City Clinical Hospital named after S.S. Yudin (Moscow), the Purulent Surgery Center of Branch No. 1 of City Clinical Hospital named after V.P. Demikhov (Moscow), and the Almazov Centre (St. Petersburg). An additional 203 X-rays were selected from outpatient Diabetic Foot clinics at the Regional Endocrinology Center (St. Petersburg) and the Endocrinology Dispensary of the Moscow Department of Health. Thus, a total of 436 X-rays from 416 patients were included in the analysis.

RESULTS

Based on the analysis of X-rays, nine primary types of typical midfoot bone displacements were identified, which in many aspects differ from those described in existing classification systems. The variants were numbered from 1 to 5, proceeding from the hindfoot toward the forefoot. In addition to the main numbering, two variants (1 and 4) were subdivided into subtypes based on the specific features of involvement within the same type. The displacement characteristics for each variant are described below.

Variant 1. Deformity (subluxation, dislocation, or fracture-dislocation) of the Chopart joint. This variant includes subtypes:

Variant 1A. Involvement of the navicular bone and talar head with the preservation of the lateral column anatomy. Typical features of this subtype include:

– defect of the talar head and/or navicular bone;

– preservation of an intact lateral column;
– no visually significant foot deformity.

Variant 1B. Simultaneous involvement of the talonavicular and calcaneocuboid joints (dorsal dislocation or subluxation of the navicular and cuboid bones). Typical features of this subtype include:

– dorsal displacement of the midfoot bones (navicular and cuboid) relative to the hindfoot bones (talus and calcaneus);
– preservation of an intact tarsometatarsal (Lisfranc) joint;
– equinus positioning of the talus and calcaneus bones without disruption of the subtalar joint alignment.

Variant 1C. Simultaneous involvement of the talonavicular and tarsometatarsal joints (dorsal dislocation or subluxation of the navicular and cuboid bones). This subtype is characterized by:

– dorsal displacement of the navicular bone along with the midfoot and forefoot bones;
– plantar dislocation of the cuboid bone at the cuboid-metatarsal joint;
– equinus positioning of the hindfoot (talus, calcaneus, and cuboid bones).

Variant 1D. Total displacement of the navicular bone with dislocation at the talonavicular and naviculocuneiform joints. This subtype is characterized by:

– plantar and/or medial dislocation of the navicular bone;
– dorsal dislocation of the medial cuneiform bone;
– dorsolateral displacement of the metatarsal bones;
– plantar displacement of the cuboid bone at the cuboid-metatarsal joint;
– dislocation of the intermediate and lateral cuneiform bones either in plantar direction together with the cuboid bone or dorsally along with the metatarsals;
– supinated positioning of the metatarsal bones;
– equinus positioning of the hindfoot.

Variant 2. Deformity (subluxation, dislocation, or fracture-dislocation) of the naviculocuneiform joint, possibly involving the lateral column at the cuboid-metatarsal joint, with progressive deformity and flattening of the medial column. This subtype is characterized by:

– destruction within the naviculocuneiform joint with preserved anatomical alignment of the Chopart joint;
– possible involvement of the lateral column at the tarsometatarsal joint;
– equinus positioning of the hindfoot.

Variant 3. Deformity (subluxation, dislocation, or fracture-dislocation) of the Lisfranc joint. This subtype is characterized by:

– subluxation of the metatarsal bones in the Lisfranc joint with valgus positioning and abduction;
– prolapse of the foot with plantar displacement;
– possible destructive changes in the Lisfranc joint;
– development or worsening of pre-existing valgus foot deformity;
– depending on the severity of destruction, possible plantar dislocation of the cuboid bone in the cuboid-metatarsal joint.

Variant 4. Isolated deformity (subluxation, dislocation, or fracture-dislocation) of the medial column involving the medial cuneometatarsal joint. This variant includes two subtypes.

Variant 4A. Isolated involvement (subluxation or dislocation) of the first cuneometatarsal joint without visible deformity in the affected area. This subtype is typically characterized by the elevation of the head of the first metatarsal bone.

Variant 4B. Dislocation of both the medial naviculocuneiform and medial cuneometatarsal joints with the displacement of the medial cuneiform relative to the other foot bones, potentially accompanied by ulceration in the area of the dislocated bone.

Variant 5. Varus deformity of the foot with fractures of the metatarsal bases and possible impaction of bones in the medial column. This variant is characterized by the following features:

– initial pes cavovarus deformity, which under conditions of neuropathic arthropathy may lead to fractures of the metatarsal bases at peak load zones, further aggravating forefoot adduction and supination, with eventual involvement of medial column bone destruction at later stages;
– development of ulcerative defects along the lateral edge of the plantar surface of the foot.

The variants of deformities and their frequency in inpatient and outpatient facilities are presented in Table 1.

A schematic representation of the deformity variants is shown in Figure 1. The variants are presented in the anteroposterior view only, for better visualization of the lesions.

Considering the specific characteristics of midfoot involvement in CN and correlating them with radiographic findings, we developed a differentiated approach to surgical management. In determining the indications for surgery, we did not rely on angular measurements associated with various types of deformities and displacements. Instead, we were guided by the Eichenholtz classification stage, the presence or absence of ulcerative defects and infectious complications, the assessment of deformity stability and its potential for progression, as well as patient complaints of limping and pain.

Given the preserved anatomical relationships in the joints of the lateral column, in variant 1A we performed restoration of the medial column length with bone grafting to reconstruct bony defects. In patients with lesions corresponding to variant 1B, we performed Chopart joint arthrodesis. In variant 1C, arthrodesis of the talonavicular and tarso-metatarsal joints was carried out. In variant 1D, arthrodesis of the talonavicular, naviculocuneiform, and lateral tarsometatarsal joints was performed. In variant 2, arthrodesis of the naviculocuneiform joint was carried out. In cases of dorsal dislocation of the 4th and 5th metatarsal bones, lateral tarsometatarsal arthrodesis was performed. Patients with variant 3 deformity underwent arthrodesis of the Lisfranc joint. In cases of isolated involvement of the first cuneometatarsal joint (variant 4A), arthrodesis of the first medial cuneometatarsal joint was performed. In patients with bone damage corresponding to variant 4B, arthrodesis of both the naviculocuneiform and the first medial cuneometatarsal joints was carried out.

Table 1

Share of each deformity variant among all examined patients

Deformity variant	Type of displacement	Inpatient, n (%)	Outpatient, n (%)	Total, n (%)
1A	Involvement of the navicular bone and talar head with the preservation of the lateral column anatomy	27 (6.10)	41 (9.50)	68 (15.60)
1B	Simultaneous involvement of the talonavicular and calcaneocuboid joints	1 (0.23)	0	1 (0.23)
1C	Simultaneous involvement of the talonavicular and cuboid-metatarsal joints	5 (1.15)	0	5 (1.15)
1D	Complete displacement of the navicular bone with the dislocation of the talonavicular and naviculocuneiform joints	93 (21.34)	59 (13.56)	152 (34.86)
2	Deformity (subluxation, dislocation, fracture-dislocation) of the naviculocuneiform joint with possible involvement of the lateral column in the metatarsocuboid joint	14 (3.21)	15 (3.44)	29 (6.65)
3	Deformity (subluxation, dislocation, fracture-dislocation) of the Lisfranc joint	75 (17.20)	32 (7.30)	107 (24.54)
4A	Isolated involvement (subluxation or dislocation) of the first cuneometatarsal joint	6 (1.40)	28 (6.40)	34 (7.80)
4B	Dislocation of the medial naviculocuneiform and medial cuneometatarsal joints with the displacement of the medial cuneiform bone	7 (1.60)	8 (1.80)	15 (3.44)
5	Varus deformity of the foot with fractures of the metatarsal bases and possible crushing of the medial column bones	5 (1.10)	20 (4.60)	25 (5.73)
Total		233 (53.40)	203 (46.60)	436 (100.00)

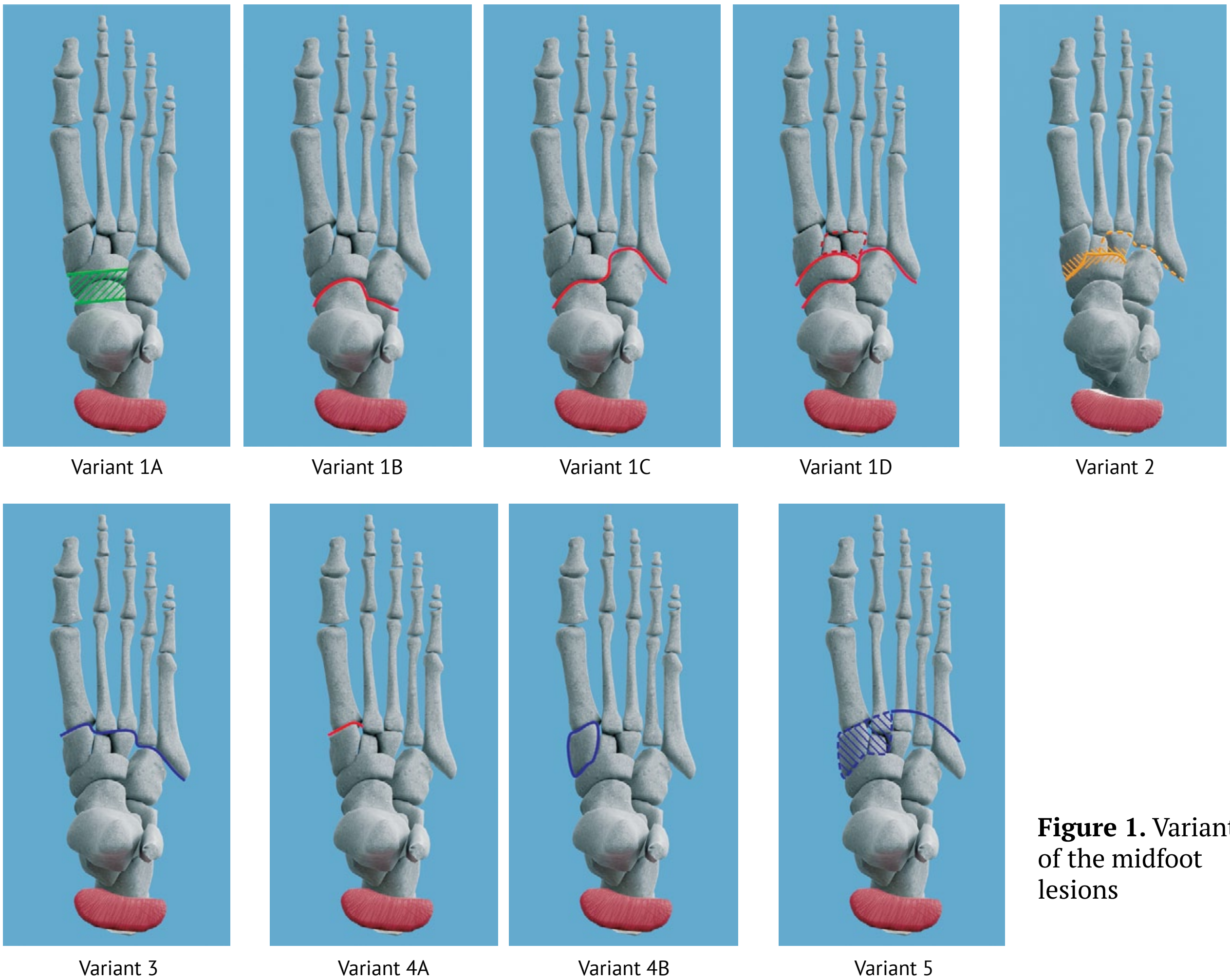

Figure 1. Variants of the midfoot lesions

The deformity variants are illustrated in X-rays (Figure 2).

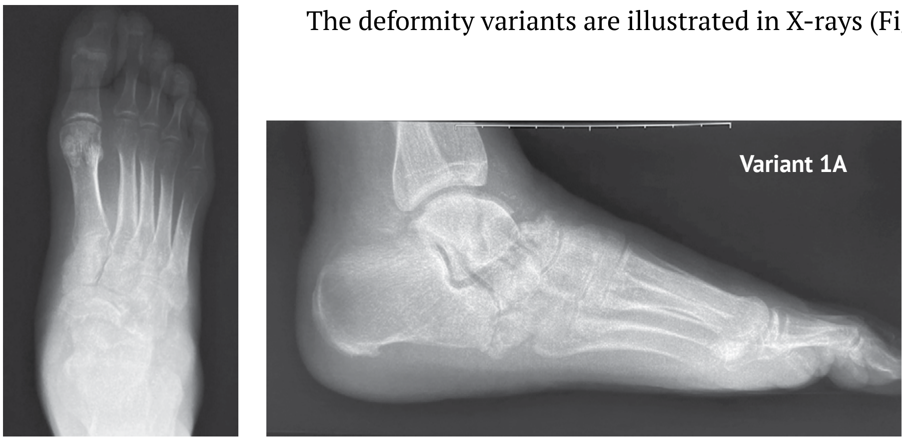

Figure 2. Deformity variants


R
Variant 1B
L
Variant 1C
L
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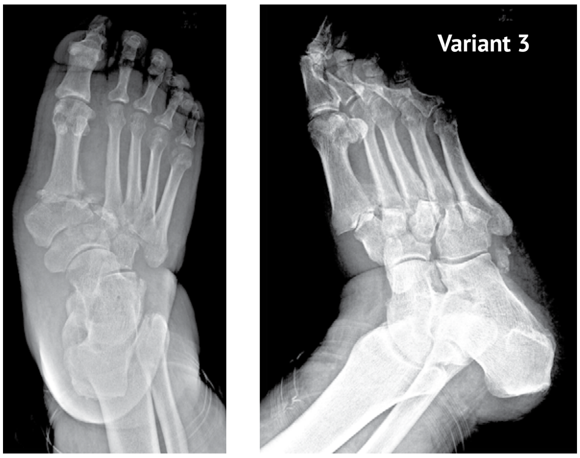
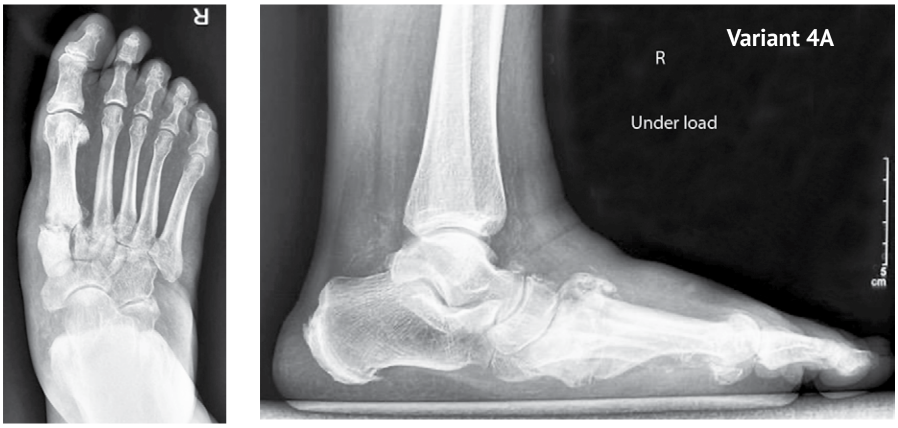
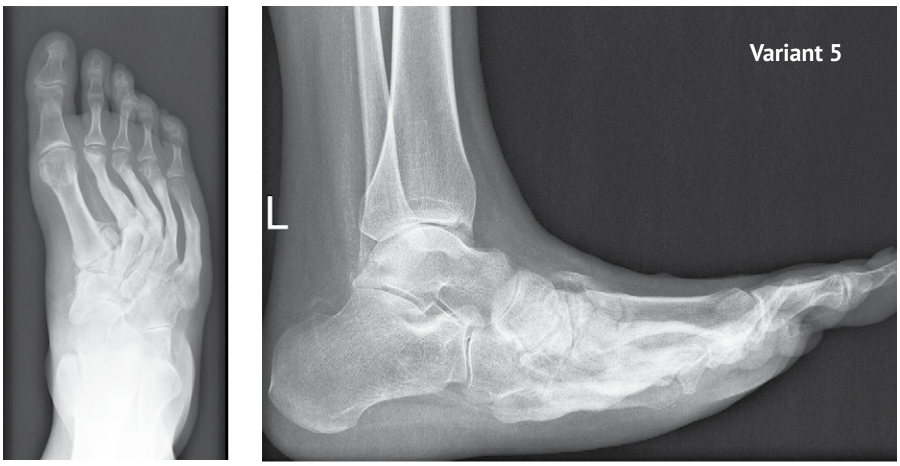
Л
Variant 1D
Variant 2





Variant 4B



In patients with varus foot deformity corresponding to variant 5 of our classification, simultaneous arthrodesis was combined with a medial column-closing wedge osteotomy to achieve deformity correction by bringing the arthrodesed surfaces into alignment.

DISCUSSION

The previously proposed radiographic classifications of midfoot deformities in CN can be conditionally divided into two groups. The first group includes early studies from the 1960s to the 1980s, a period when the incidence of CN increased, and, as a poorly understood complication of various diseases, it attracted the attention of specialists. Therefore, the publications from that period were primarily descriptive in nature. They mainly addressed three questions: what types of lesions are encountered, how frequently they occur, and, to some extent, what mechanisms might contribute to the development of specific deformities. Given that CN is a relatively rare condition, it is evident that the sample sizes in these studies were small, and some of them more closely resembled case reports. For example, in the study by J. Harris and P. Brand, 147 patients were evaluated without subdivision by foot region [16]. R. Cofield et al. reported on 38 patients, of whom 18 had involvement of the Chopart joint and 20 had medial column involvement [17]. The study by G. Sammarco and S. Conti analyzed X-rays of 26 patients [18]. The issue of limited sample representativeness was highly relevant at this stage; even in the comprehensive study by L. Schon et al., 109 patients were included, of whom only 89 had *diabetes mellitus* [19]. Furthermore, in another article by L. Schon et al., to illustrate the pattern 4 deformity, X-rays of a patient with peritalar dislocation were shown – this corresponds to hindfoot involvement and is not associated with destructive changes in the calcaneocuboid joint [20]. The studies of the first group reflected the accumulation and systematization of knowledge and were conducted by clinicians, mainly surgeons. A kind of culmination of this period is the classification proposed by L. Sanders and R. Frykberg, in which five types of CN lesions were identified for the first time [21]. Notably, this classification was also the first to suggest different prognoses depending on the type of lesion, marking a shift from descriptive classifications to clinical, radiological, and outcome-oriented systems [12, 22].

Unlike previously published studies, the aim of our research was to systematize the radiographic patterns in such a way that the identified variants would enable a differentiated surgical approach to treatment. In addition, we focused on the most common and limb-threatening type of lesion — midfoot involvement. To achieve this goal, it was necessary to analyze a significantly larger number of X-rays than in previously published works; therefore, we designed the study as a multicenter investigation. Both outpatient and inpatient facilities participated in our study, which allowed us to broaden the scope of the pathology and to identify less common variants. Furthermore, during the study planning phase, we hypothesized that lesion patterns in outpatient and hospital settings might differ. This assumption was only partially confirmed: deformities of types 4A and 5 were somewhat more common in outpatient practice, while types 1D and 3 were more frequently encountered in inpatients. For the remaining variants, we found no significant differences.

Arguably the most detailed classification of midfoot lesions is the system proposed by L. Schon et al. [19]. The 24 variants identified by the authors reflect, on the one hand, the diversity of patterns of bone destruction and displacement. On the other hand, in our study we identified several variants not described in the aforementioned publication, which is most likely due to the limited sample size in the study by L. Schon et al. Moreover, in our view, this level of detail poses a challenge for practical clinical use.

The classification we propose is based on a comparison of the radiographic findings at the time of the patient's initial presentation with the known patterns of bone displacement resulting from muscle and tendon pull as well as external loading during walking [15]. The key patterns we considered in developing our classification are outlined below.

The lateral column of the foot includes the tarsometatarsal and calcaneocuboid joints. The calcaneocuboid joint, formed by the calcaneus and the cuboid bone, has a saddle-shaped configuration and is stabilized by the dorsal calcaneocuboid ligament, a relatively thin band located on the lateral side, and the stronger plantar calcaneocuboid ligament, which consists of two distinct layers.

The metatarsocuboid joint is formed by the flat articular surfaces of the cuboid bone and the bases of the fourth and fifth metatarsal bones. Its ligamentous support is relatively limited and consists of plantar and dorsal tarsometatarsal ligaments. Additionally, the metatarsal bones are interconnected by dorsal and plantar intermetatarsal ligaments. The tendon of the peroneus brevis muscle attaches to the styloid process of the base of the fifth metatarsal and the base of the fourth metatarsal, while the tendon of the peroneus tertius muscle inserts into the proximal metadiaphysis of the fifth metatarsal bone.

In our analysis of X-rays, a higher incidence of dislocation was observed in the tarsometatarsal joint (87.4%) compared to the calcaneocuboid joint (12.6%). This is likely due to the robust ligamentous support stabilizing the calcaneocuboid joint, which resists displacement. The presence of the anterior process of the calcaneus also limits superior displacement of the cuboid relative to the calcaneus. These findings can be explained by the relatively underdeveloped ligamentous apparatus of the tarsometatarsal joint compared to the calcaneocuboid joint, as well as the pull of the peroneus brevis and peroneus tertius muscles, and the presence of obliquely oriented articular surfaces between the cuboid and the fifth metatarsal bones. Additionally, the lateral cuneiform is situated slightly more anteriorly and dorsally relative to the cuboid, which exerts axial pressure on the cuboid during weight-bearing and further promotes plantar displacement of the metatarsocuboid joint. Simultaneously, the continued pull of the Achilles tendon induces an equinus position of the calcaneus, talus, and cuboid complex, thereby increasing stress on the ligamentous structures of the tarsometatarsal joint and further driving the cuboid bone in a plantar direction.

The anatomy of the medial column is more complex due to the presence of multiple structures and includes the talonavicular, naviculocuneiform, and cuneometatarsal joints.

The talonavicular joint is formed by the head of the talus and the concave articular surface of the navicular bone. It is stabilized by the dorsal talonavicular ligament, which normally prevents plantar and medial displacement of the navicular bone, as well as by the calcaneonavicular ligament. On the plantar surface, the tendon of the posterior tibial muscle attaches to the navicular tuberosity and has additional insertions on all three cuneiform bones and the base of the fourth metatarsal.

The naviculocuneiform joint is flat in shape and formed by the navicular and cuneiform bones. It is stabilized by plantar and dorsal naviculocuneiform and intercuneiform ligaments. On the plantar surface of the medial cuneiform, the tendon of the anterior tibial muscle inserts.

The cuneometatarsal joints consist of three separate articulations formed by the articular surfaces of the bases of the first, second, and third metatarsal bones and the medial, intermediate, and lateral cuneiform bones, respectively. The arrangement of the cuneiform bones creates a recess or mortise-like socket for the base of the second metatarsal. Each of these joints is reinforced dorsally and plantarly by ligaments extending from the base of the metatarsal to the corresponding cuneiform bone. In addition, the joints are stabilized by a robust ligamentous complex: medially, by a strong ligament, considered the key stabilizer of the Lisfranc joint complex, extending from the lateral surface of the medial cuneiform to the base of the second metatarsal; and laterally, by cruciate-shaped ligaments connecting the base of the second metatarsal to the lateral cuneiform and the base of the third metatarsal to the intermediate cuneiform.

The involvement of the talonavicular joint results in the medial and plantar displacement of the navicular bone due to the pull of the posterior tibial tendon, despite the tendon's multiple insertion points. The degree of navicular displacement may range from a slight subluxation to a complete dislocation and can be accompanied by fracture. This variability is likely related to inherent differences in foot morphology and biomechanics. The pull of the anterior tibial tendon causes the posterior displacement of the forefoot and midfoot, with the cuneiform bones overriding the displaced navicular. Considering that patients often have markedly reduced sensation, continued axial loading in the presence of fracture-dislocations combined with preserved rocking movements in the affected joint contributes to the erosion of the proximal edges of the cuneiform bones, leading to the formation of bony defects of varying size.

Lisfranc joint lesions cause changes similar to those observed in talonavicular joint involvement. Due to the pull of the posterior tibial tendon, the medial cuneiform and navicular bones are displaced medially and plantarly, while the metatarsal bones are dislocated dorsally and posteriorly as a result of contraction of the anterior tibial muscle, and also laterally due to the pull of the peroneus longus tendon. We identified two displacement patterns of the intermediate and lateral cuneiform bones: in the first pattern, all three cuneiform bones shifted in medial and plantar direction as a single unit; in the second, only the medial cuneiform and metatarsals were displaced dorsally, whereas the intermediate and lateral cuneiform bones prolapsed in the plantar direction, locally increasing pressure on the soft tissues and potentially leading to ulcerative defects.

Such deformity is often described in the literature as a rocker-bottom foot deformity [23]. However, this terminology is somewhat inaccurate, as the deformity occurs not only in the sagittal plane but also in the transverse plane due to the abduction of the forefoot.

Analyzing X-rays, we identified cases where damage to the medial column, manifested as destruction of the talar head, navicular, and medial cuneiform bones with the preservation of the lateral column, was accompanied by the development of an adduction contracture. The presence of forefoot adduction is biomechanically unjustified, which prompted us to perform additional radiographic assessments. Comparing images with the contralateral healthy foot, we found that patients with this deformity originally had a mild varus deformity with a pronounced longitudinal arch and forefoot adduction. With progression of arthropathy, ligamentous structures of the medial column were compromised, resulting in “crushing” of the talus, navicular, and medial cuneiform bones and subsequent formation of the adduction contracture. Pathological fractures occurred at the apex of the deformity, around the bases of the third, fourth, and fifth metatarsal bones, leading to the lateral column instability and further adduction and supination of the foot.

The combined consideration of the aforementioned changes enabled us to develop a differentiated surgical treatment strategy based on the specific deformity pattern. The system we proposed represents the first attempt to link classification with a practical therapeutic algorithm for midfoot CN, with no existing analogues published to date. It is evident that our proposed algorithm requires long-term validation in clinical practice and may be refined as more data are accumulated and patients are followed prospectively. This is particularly relevant for the less common deformity variants.

CONCLUSION

As a result of systematizing X-rays of feet with midfoot Charcot neuroarthropathy and considering the mechanics of dislocation formation, we proposed a new classification of midfoot lesions. It comprises five main types, with subtypes in types 1 and 4. The proposed classification is intended to guide the selection of key reconstructive surgical interventions for this pathology.

DISCLAIMERS

Author contribution

Osnach S.A. — study concept, data acquisition, analysis and interpretation, drafting the manuscript.

Protsko V.G. — data analysis and interpretation, editing the manuscript.

Obolenskiy V.N. — data acquisition, analysis and interpretation, editing the manuscript.

Bregovsky V.B. — data acquisition, study concept, drafting the manuscript.

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Zagorodniy N.V. — 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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