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**Review article**

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# *Foot deformities in patients with diabetic foot disease (literature review)*

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***Abstract***

**The objective** was to review the orthopaedic literature on treatments of diabetic foot disease. **Material and methods** PubMed, CyberLeninka, Google Scholar, Scopus, Medline, eLIBRARY were searched. Studies in English and in Russian that reported foot deformities in the pathogenesis of diabetic foot disease and orthopaedic correction methods in the complex treatment of this late complication of diabetes mellitus were included for review. All study designs were considered. The search was produced using the following terms: diabetes mellitus, foot deformities, diabetic foot syndrome, orthopaedic treatment, osteotomy, metatarsophalangeal arthroplasty, achilles tendon lengthening. Literature sources reporting methods of orthopaedic correction of foot deformities in isolation from the diabetic foot syndrome and literary sources reporting manifestations of the diabetic foot syndrome without description orthopedic methods of treatment (surgery for purulent complications, vascular surgery, hypoglycemic therapy) were excluded from the study. **Results** The literature review allowed us to evaluate the role of orthopaedic treatment of foot deformities in patients with diabetic foot syndrome to be addressed either conservatively or surgically. The effectiveness of conservative methods has long been reported in studies with higher degree of evidence. Surgical correction of DFS through orthopaedic interventions has not been covered in such detail. **Conclusion** The literature review focused on the topical issue at the junction of various medical specialties. The results of treatment reported by Russian and foreign authors were analyzed. "Blind spots" in the literature were explored, goals for subsequent research delineated.

**Keywords**: diabetes mellitus, foot deformities, diabetic foot disease, orthopaedic treatment

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**The objectives** of the study are to search and review the literature allocating foot deformities in the pathogenesis of diabetic foot syndrome and describing the role of orthopaedic correction in the treatment of this late complication of diabetes mellitus.

## MATERIALS AND METHODS

Studies in English and in Russian that reported foot deformities in the pathogenesis of diabetic foot disease and orthopaedic correction methods in the complex treatment of the late complication of diabetes mellitus were included for review. PubMed, CyberLeninka, Google Scholar, Scopus, Medline, eLIBRARY were searched. All study designs were considered. The search was produced using the following terms: diabetes mellitus, foot deformity, diabetic foot syndrome, orthopaedic treatment, osteotomy, metatarsophalangeal arthroplasty, achilles tendon lengthening. Literature sources reporting methods of orthopaedic correction of foot deformities in isolation from the diabetic foot syndrome and literary sources reporting manifestations of the diabetic foot syndrome without description orthopaedic methods of treatment (surgery for purulent complications, vascular surgery, hypoglycemic therapy) were excluded from the study.

## RESULTS

*The role of foot deformities in the pathogenesis of diabetic foot syndrome*

Diabetes mellitus (DM) is one of the most common noncommunicable diseases in the world. The number of diabetic patients increased fourfold from 1980 to 2014: from 108 million to 422 million among adult population, which was 4.7 and 8.5 % of the world population, respectively [1]. In the Russian Federation, the number of DM patients increased by 2.2 times – from 2.043 million [2] to 4.58 million people between 2000 and 2019 [3]. The diabetic foot syndrome (DFS), one of the most common complications of DM, combines pathological changes in the peripheral nervous system, arterial and microcirculatory beds and the osteoarticular apparatus of the foot which pose a direct threat to the development of ulceration, necrosis and gangrene [4].

In 2016, the prevalence of DFS in the Russian Federation among DM patients was 4.7 % of type 1 DM, 1.9 % type 2 DM. The prevalence of DFS in the Russian Federation in the dynamics of 2013→2016 tended to decrease with type 1 DM being 506.3→ 473.6; Type 2 DM being 214.60→194.8 per 10 thousand adults. Various forms of DFS type 1 diabetes include neuropathic DM with trophic ulcer, 41.6 %; neuropathic (Charcot's foot), 17.9 %; neuroischemic, 28.3 %; ischemic, 12.2 %; Type 2 DM: 41.6, 7.4, 32.4, 18.5 %, respectively [5]. A high prevalence of musculoskeletal diseases is reported among adult population with the incidence of musculoskeletal diseases being 142.0 cases in 2012, 145.1 cases per 1000 people in 2014 with a slight decrease to 141.4 in 2016 [6]. Static foot deformity (SFD) is one of the most common in this group of diseases. There are different data reported. Russian researchers report the incidence of hallux valgus and transverse flat feet in 70 % of the population [7]. Some foreign authors suggest the condition occurs in 37 % [8]. The older the patient, the more common the orthopedic pathology [9]. DM patients mostly belong to the older age group.

Differences between various foot deformities in DFS patients were not explored. Russian researchers offered a classification that differentiated between two groups including patients with static foot deformities who may not have DM and post-amputation deformities and Charcot foot (diabetic neuroosteoarthropathy). The first group included hammertoe and claw toe, transverse flattening, valgus abduction of the first toe, Taylor's deformity, restricted dorsiflexion of the foot, etc. Deformities of the second group were considered as complications of DM in neglected clinical cases [10].

Study review indicated a decrease in the elasticity and strength of the muscles of the distal lower limbs due to degenerative fibrous and fatty changes. The distally located muscles of the foot (interosseous, vermiculare) are more affected than the proximal flexors and extensors of the toes, soleus and gastrocnemius muscles. Muscle tissue in the distal segments of the limbs are characterized by heterogeneous changes. The tone of the proximal muscles prevail with impaired muscle and tendon balance in the metatarsophalangeal and interphalangeal joints causing hammertoes [18, 19]. Static foot deformities resulted from decreased elasticity of the soleus and gastrocnemius muscles caused by neuropathic degenerative changes. Restricted dorsiflexion in the ankle joint leads to increased pressure on the plantar surface of the forefoot and can cause appearance or aggravation of existing static deformities formation of a neuropathic ulcer at the site [20].

Associations between the appearance of ulcerative skin defects at the site of increased mechanical impact in patients with distal neuropathy have not been fully understood. A.S. Sudnitsin et al. [11] reported characteristic skin changes in the feet of patients with distal neuropathy. These changes manifested in the form of pseudocarcinomatous hyperplasia of the skin and increased density of microvessels and speed of capillary blood flow, parakeratosis, thinning of the dermis, loss of adipose tissue and degeneration of nerve conductors in most of the nerve trunks of the dermis that was accompanied by impaired temperature and pain sensitivity.

E.V. Artemova et al. [12] report skin changes in patients with diabetic neuropathy. The resistance of the skin to mechanical stress is associated with the strength of the stratum corneum and achieved due to the cellular attachments of keratinocytes. The integrity of the skin, the resistance to mechanical stress at sites of greater mechanical stress that accompany static deformations, is regulated by complex neurohumoral processes that are disturbed in diabetic neuropathy with reduced differentiation of keratinocytes and production of keratin [13]. There is a similarity in injury to the nervous tissue that accompanies leprosy, syphilis, poliomyelitis, alcohol abuse, traumatic spinal cord injuries and diabetic neuropathy [14]. However, DM is the most common cause of distal neuropathy and its sequelae such as chronic ulcers. The prevalence of neuropathy among DM individuals varies between 28 and 65 % depending on the duration of the disease and diagnostic methods [15].

Patients with peripheral neuropathy tend to develop ulcerative defects at sites of increased pressure and friction in the presence of static foot deformities that fail to heal with greater mechanical impact [16, 17]. Ulcerative defects are commonly seen on the sole at the heads of the metatarsal bones (medium with transverse flattening, first and fifth with hyperarch and Taylor's deformity); on the medial aspect of the foot at the first metatarsophalangeal joint with valgus abduction of the first toe; on the back of lesser toes and at the tuberosity of the nail phalanx with hammertoes [21]. However, there are no data in the literature regarding correlation of diabetic neuropathy and foot deformities, a quantitative analysis of this phenomenon. The specific manifestations of the clinical picture and the specific features of the pathogenesis of the condition encourage doctors explore the possibilities with orthopaedic treatment of the pathology. There are surgical and therapeutic approaches to the orthopaedic treatment of static foot deformities in DFS patients.

*Conservative treatment*

Conservative methods of orthopaedic treatment of DFS of the feet have been used for a long time in Russia and are included in the official guidelines for the treatment of the cohort of patients [22]. Conservative treatment using shoes, insoles, orthopaedic devices is based on the classification of patients according to the risk of DFS and the need for correction and off-loading. According to the classification of the International

Working Group on the Diabetic Foot (IWGDF) patients with diabetic peripheral neuropathy in combination with foot deformities are at medium risk. Patients with neuropathy in combination with amputations within the foot or a history of ulcers, severe deformities can be attributed to a high-risk group [23]. Shoes to be used by patients with neuropathy and foot deformities are characterized by a rigid sole with rocker sole or roller sole, a soft top without a toe cap; the width of the shoe is not less than the width of the foot; bevelled front edge of the heel (reduces the likelihood of getting injury and falls); sufficient depth for a special insole; shoes should be selected by a specialist [24, 25].

Shoes with the characteristics described above have a thick (9-10 mm), soft and shock-absorbing insole to allow modeling of the arches of the foot and effective off-loading the plantar surface with an average duration of effective service life of 6-12 months. The use of insoles made of soft, but shock-absorbing materials (polyurethane foam, etc.) has been reported [26]. High-risk patients can use custom-made orthopaedic shoes and insoles that would model the arches of the foot and effectively off-load the risky ulceration sites [27, 28].

Bus S.A. et al. and Ulbrecht J.S. et al. demonstrated a peak pressure relief by 30 % in regions at risk of ulceration with use of orthopaedic shoes and an insole designed for DFS patients as compared with conventional shoes [29, 30]. The use of various orthopaedic devices (hammertoe correctors, metatarsal padding, etc.) in DM patients is often associated with a risk of skin injury. Therefore, the selection of orthopaedic correctors should only be strictly supervised individually by a specialist. Custom-made silicone toe deformity correctors are most widely used [31].

Special shoes with a variety of size adjustments and a “roller sole” are used to treat ulcers off-loading the forefoot. The so-called "low shoes", also known as "Barouk's shoe" (Barouk L.S. Use of a Postoperative Shoe without Forefoot Support, Comparative Statistical Study. Actualites de medecine et chirurgie du pied, 1986) can be used for the purposes. Total Contact Casts (TCC) have been shown to be extremely effective in off-loading the diabetic foot in the absence of infection and critical ischemia [23, 32, 33].

The TCC is an off-loading immobilization dressing made of rigid and semi-rigid polymeric materials to be applied from the tibial upper third to the tips of the toes (along the plantar surface). The foot can be off-loaded with TCC by transferring about 30 % of the weight from the foot to the tibia increasing the supporting surface through a uniform pressure distribution on the supporting surface of the foot and decreasing the weight from areas of increased mechanical impact by 40–80 %, reducing friction to the ulcer, reducing edema of the limb thus, providing moderate compression and exerting a disciplinary effect on the patient.

An active infectious process of the foot and gangrene are absolute contraindications to the use of TCC. TCC can be removable if needed with the cut made along the entire length and fixed with a plaster, Velcro tape, elastic bandage and can be taken off for dressings to control ulceration healing [34, 35]. Effective healing can also be achieved by combination of a non-removable TCC and an off-loading boot with a roller sole. This combination leads to ulceration healing improved by 17–43 % being shorter by 8–12 days than that with the detachable option or an off-loading boot [36–38]. Complications of TCC occur in 0–20 % of cases including new superficial ulcers caused by the bandage, pain of major joints of the lower limbs caused by redistribution of the load during locomotion and instability at the gait [39, 40]. Complex orthopaedic products (Aircast, Walker) are an alternative treatment with a similar effect of TCC; however, the price is many times higher than the cost of TCC, and they are not readily available in the Russian Federation [41–42].

*Surgical treatment*

Resection arthroplasty, resection of the metatarsal head, osteotomy of the foot bones, tenotomy of the flexor and extensor tendons of the toes, Achilles lengthening are used to address DFS due to the correction of SFD.

*Tenotomy of the flexor and extensor tendons of the toes can be produced with a thick needle through skin punctures*. The less traumatic surgical treatment of DFS can be applied for cases with a neuropathic ulcer located on the dorsum of the proximal interphalangeal joint or at the tuberosity of the nail phalanx with a hammertoe of the II–IV digits. The manipulation results in a decreased mechanical impact on the ulceration. Tenotomy of the extensor tendons is performed on the dorsal surface at the level of the metatarsophalangeal joint, and the tenotomy of the flexors is produced on the plantar surface at the level of the interphalangeal joints [43, 44]. The method facilitated healing of neuropathic ulcers in 97 % of cases within 4 weeks. Infection was seen in 1 %, recurrence noted in 6 % of cases [45, 46].

*Lengthening of the triceps muscle with Achillotomy using Nocke technique or transection of the aponeurosis of the gastrocnemius*. The method of surgical treatment is aimed at reducing pressure on the plantar surface of the forefoot [47, 48]. The Nocke technique involves transection of the Achilles tendon at half the diameter using three / four skin punctures in a checkerboard pattern followed by redressing. The intersection of the aponeurosis of the gastrocnemius is produced in the transverse direction (Strayer technique) or wedge-shaped / curved Vulpius technique using a 3-5 cm approach on the posterior or posterior medial surface at the level of the middle and lower third of tibia. Ulcer healing after triceps lengthening and use of TCC was observed in 100 % of cases versus 88 % of conservative treatment and within a shorter period of time: 41 days versus 57.

Complications observed included ulcer transfer to the plantar surface of the heel (16 %), infection (2 %) and Achilles tendon rupture (no healing) 13 %) [49 , 50].

*Resection of the metatarsal head* in the treatment of DFS can be used to locally reduce the mechanical impact on the plantar surface. The surgical treatment is more common for chronic osteomyelitis of the metatarsal head with the ulcer reaching the bone. The approach is produced from the plantar or lateral surface of the foot (with resection of the head of the fifth metatarsal). Resection of the heads of all metatarsals can be performed for multicomponent complex deformities of the forefoot and in the presence of more than one ulcer [51]. Healing is observed in 100 % of cases versus 60 % of conservative treatment with TCC within 70 days versus more than a year with conservative treatment. Infection developed in 12 % of cases [52, 53].

*Resection arthroplasty of the first metatarsophalangeal joint according to the Keller* can be used in the treatment of neuropathic ulcers of the first toe. In this case, the increased mechanical impact is caused by stiffness of the first toe in deforming osteoarthritis of the metatarsophalangeal joint. The technique involves resection of the base of the proximal phalanx using an incision on the medial / medial-dorsal surface of the foot. Healing is observed in 100 % of cases within 24 ± 9.9 days, versus 67.1 ± 17.1 days in 80 % in cases of conservative treatment. The infection is seen in 16.5 % [54–56].

Modern technologies of orthopaedic surgery can be used for the foot deformity correction. Treatment of neuropathic ulcers of the plantar surface of the forefoot under the heads of lesser metatarsal bones is performed using minimally invasive osteotomies. The osteotomy is produced at the level of the distal metaphysis of the metatarsal using a special cutter through a skin puncture and the head is shifted to the dorsum removing this zone from the load. No bone fixation is implied. The median healing time for ulcers was 4–17 weeks with no recurrences reported.

Postoperative wound is reported to get infected in one case. No other complications are described [57]. More possibilities of minimally invasive orthopedic surgery have been recently reported in the treatment of static foot deformities in DFS patients [58–60]. Less favorable results are described with "open" osteotomies of the metatarsal bones with closing wedge to allow elevation of the head of the corresponding metatarsal bone decreasing the mechanical impact on the ulcer. Fixation is produced with crossing Kirschner wires or screws. Ulcer healing is observed in 95 % of cases, on average 40 days after surgery. Complications are noted in 68 % including Charcot's diabetic neuroosteoarthropathy (32 %) and deep wound infection (14 %) [61].

## DISCUSSION

There is a paucity of findings in the literature on the correlation of the extent of neuropathy and the severity of deformities, the severity of deformity and the degree of DFS manifestations: the size of neuropathic ulcers and the depth. The relationship of these phenomena is reported but a quantitative prognosis of the course of the disease is difficult based on the available data on the patient (duration of diabetes, the severity of neuropathy, severity of deformities and presence of neuropathic ulcers).

Our clinical guidelines for the treatment of complications of DM do not feature recommendations for the surgical correction of foot deformities as a method of treating DFS. Clinical guidelines of the international working group on diabetic foot describe conservative treatments of ulcers as the first level of evidence management, and surgical treatments as the second level due to the scarce number of randomized clinical trials. Meanwhile, conservative treatment requires a high level of adherence to treatment with long-term use reducing the quality of life and being expensive for the patient.

As a disabled individual he/she can reimburse the expenses on purchase or manufacture an orthopaedic device. There are no reports describing specific examination protocol to be used by practicing orthopaedic surgeons, indications and contraindications for the use of a particular treatment method. The main indication for surgical treatment is failed conservative therapy. Diagnostic methods that would allow identification of an optimal method of treatment are not reported. There is a paucity of publications reporting technical issues, details of surgical interventions, description of pre- and postoperative period for weight-bearing (orthopaedic regimen). Information on rehabilitation of patients at a medium and long terms is poorly presented. The use of TCC or other means of immobilization is considered as an isolated method of treatment. There is no description of the use of TCC in the postoperative period as a stage of immobilization and rehabilitation.

There are no indications for a reasonable choice of the method of bone fixation with osteotomies analyzing the degree and type of deformity to correlate with the technique and volume of the operation. Literature reviews on a particular treatment method sometimes include works that differ in publication time by more than 20 years. Studies conducted with such a time gap may not have a sufficiently comparable pattern of results. The analysis of the complications is not presented to describe the alleged causes, methods of the treatment and prevention. Orthopaedic methods of treatment are likely to be considered in isolation in most cases as a method of treating manifestations of DFS and not of correcting or compensating for existing deformities that would facilitate healing of neuropathic ulcers.

## CONCLUSION

Surgical and conservative methods of orthopaedic treatment are effective in respect of manifestations of DFS. Despite the relationship of static foot deformities with manifestations of DFS, the effectiveness of surgical deformity correction conservative treatment remains the preferred orthopaedic treatment of DFS to compensate for impaired biomechanics of the foot.

There has been an increase in the number of reviews reporting surgical orthopaedic treatment of DFS with deformity correction including the techniques described in practical recommendations that indicated an increase in interest in this area. Creation of a protocol for examining patients with foot deformities and diabetic foot syndrome, publication of research studies with higher level evidence would facilitate objective approach to orthopaedic treatment of DFS including greater possibilities of conservative and surgical techniques.

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*Bardyugov P.S. – collection and processing of materials, analysis of the data obtained, writing the text.*
*Parshikov M.V. – the concept and design of the study, writing the text.*

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