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Review article

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Arthroplasty in the treatment of patients with avascular osteonecrosis of the talus: literature review

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Abstract

Introduction The paper discusses the main issues of treating patients with avascular osteonecrosis of the talus. The importance of the problem of treating patients with avascular osteonecrosis of the talus is explained by its high incidence, the difficulty of diagnosis in the early stages of the disease and poor treatment results with the use of traditional methods. **Purpose** Based on the analysis of foreign and domestic literature, to determine the current state of the problem of surgical treatment of avascular osteonecrosis of the talus and to identify the range of possible surgical interventions in patients with the pathology under the study, to analyze in historical retrospect the arthroplasty of the talus bone due to its total involvement in the pathological process. **Materials and methods** The review analyzes the literature on this topic, in which 79 foreign studies, published in the period from 1911 to 2021, were selected along with 9 domestic publications for the period from 2011 to 2021. PubMed, MedLine and eLibrary Internet resources were used to search for publications. **Results** Based on the literature data, the issues of the history, etiology, pathogenesis, systematization and diagnosis of this disease are highlighted. The existing methods of treatment have been analyzed along with their advantages and shortcomings. **Conclusion** The analysis of current professional literature has demonstrated the preference of the method of talus bone arthroplasty in its total avascular osteonecrosis, in comparison with arthrodesis of the joints of the hind foot of various extent. Nowadays, the technology of arthroplasty of the talus bone is scientifically sound, biomechanically confirmed and effective for the treatment of patients with avascular osteonecrosis of the talus bone and its consequences, while the demand for this technology has been growing all over the world. There is a constant improvement of tools, technologies, methods and materials.

Keywords: avascular necrosis, aseptic necrosis, osteonecrosis, osteochondroplasty, arthrodesis, endoprosthesis, ankle joint, talus bone, ceramic endoprosthesis, cobalt chromiumtalus, bone endoprosthesis, zirconia ceramics

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INTRODUCTION

This paper is a continuation of the scientific work carried out by the author Kuznetsov V.V. within the framework of the dissertation study "Treatment of osteochondral lesions of the talar bone (hereinafter TB) by the original method of osteochondroplasty", dedicated to the treatment of patients with avascular osteonecrosis of the talus (hereinafter AOTB) with local osteochondral defects that was defended in 2018 [1]. In this work, the authors highlight the problem of treating patients with a total talar avascular osteonecrosis.

The treatment of AOTB is a serious challenge for the orthopaedic surgeon. Avascular osteonecrosis of the talus is a "disfiguring" consequence of fractures, fracture-dislocations and injuries of the talus, and the likelihood of AOTB increases with the severity of the injury and associated damage to the already "fragile" blood supply to the talus. The outcome of AOTB is the reason for the high incidence of patients' disability. In addition to post-traumatic causes of the development of this disease, alcoholism, steroid use, dyslipidemia, and various idiopathic factors may be causes of AOTB. The shortcomings of modern methods of treating AOTB, such as the high traumatic nature of traditional surgical methods, irreversible loss of movements in the functionally significant joints of the foot and ankle, a high risk of nonunion, a high incidence of residual deformities, the need for long limb immobilization and rehabilitation periods, are the actual reasons for the study of this pathology. A natural question arises: how to overcome the existing shortcomings and improve the results of treatment of patients with AOTB? A potential solution to this problem is total talar arthroplasty.

We present a clinical and historical review of the evolution of treating patients with AOTB and describe the ways of development and improvement of the main methods of treatment in the historical aspect with an assessment of their advantages and shortcomings.

Purpose Based on the analysis of foreign and domestic literature, to determine the current state of the problem of surgical treatment of avascular osteonecrosis of the talus and to identify the range of possible surgical interventions in patients with the pathology under study, to analyze in a historical retrospective the method of total arthroplasty of the talus in its total involvement into the pathological process.

MATERIALS AND METHODS

To analyze the topic, 79 foreign studies were selected, published from 1911 to 2021, as well as 9 domestic studies published from 2011 to 2021. The Internet resources PubMed, MedLine and eLibrary were searched for literature.

RESULTS

Anatomical features of the talus, the etiology of avascular osteonecrosis of the talus

It is well known that the talus bone (hereinafter TB) (lat. talus; syn. supracalcaneus, astragalus) is the second largest among the bones of the tarsus, forming a movable unit that performs a complex set of active and passive movements at the ankle level.

An important feature of the anatomy of the talus is that the area covered by articular cartilage, according to some authors [2, 3], reaches 70 % of its surface. This explains the peculiarities of blood supply, which is carried out through a network of anastomoses of regional arteries. So, the anterior tibial, posterior tibial and peroneal arteries (the main branches of the popliteal artery) supply blood to the ankle joint and the distal foot. Damage to the mechanism of talus blood supply also plays a major role in degenerative lesions, primarily for AOTB [4, 5].

Disturbance of the blood supply to the bone tissue of the talus may result from both traumatic injury and impaired arterial inflow or venous outflow. Many authors describe bone tissue necrosis in AOTB as a result of ischemia [6]. Most often, the site of necrosis in the initial stages is a zone of resorption, a local defect, which subsequently becomes denser (sclerosed), collapses. On the contrary, the defect of the body of the talus progresses, its size depends on the volume of the affected bone tissue. The histological examination of the necrotic talus showed the presence of thin bone tissue, almost devoid of cells; non-nuclear cells were found in the part of the bone that retained its architectonics. Necrotic masses were visible in some places. Macrophages were detected. In the regeneration zone, tissue fibrosis was observed, characterized by the presence of fibrin fibers and rare spindle-shaped cells. The process of bone necrosis was associated with practically intact cartilage tissue; in some places necrotic changes penetrated into the cartilage tissue. Detachment of cartilaginous tissue from the bone was seen [7]. Thus, injuries, injuries and fractures of the talus are often accompanied by blood supply disorders, thus causing AOTB.

The predicted incidence of traumatic osteonecrosis associated with talus neck fractures is reported to be 0 % to 10 % for Hawkins type I fractures [8] and > 60 % for type III fractures [9]. Associated displacement in these fractures, and also, dislocation of the talus in the subtalar and ankle joints increases the likelihood of developing AOTB up to 100 % [10]. Fractures of the talus are rare and usually result from high-energy injury mechanisms such as a fall from a height or a car accident. A number of studies provide data on injuries of the talus in 0.1-2.5 % in relation to all fractures of the bones of the skeleton; however, the true incidence of injuries to the talus is still unknown [11]. The rarity of this trauma partly explains the historically poor outcomes and high complication rate, as there is little data in the current literature to guide the management of patients with talus injuries.

Avascular osteonecrosis of the talus has also been described in the absence of trauma and has been associated with such somatic disorders and diseases in the body such as corticosteroid excess [12-16], chronic alcoholism [17], hyperuricemia [18], systemic lupus erythematosus and pancreatitis [19].

Clinical manifestations and diagnosis of avascular osteonecrosis of the talus

To diagnose AOTB in the early stages can be challenging and an orthopedic traumatologist should anticipate this, especially in traumatic cases with a history of significant displacement of the talus body. The analysis of the problem found that there is no alertness among clinicians in diagnosing the disease in the early stages. There is a need for clear guidelines for the diagnosis and treatment of patients with AOTB [20-22]. The clinical picture in the early stages of the AOTB disease resembles an arthritic syndrome without pathological changes in radiographs of the ankle joint, while the formation of talus cysts, varus/valgus deformity of the foot, "disfiguring" osteoarthritis of the ankle, subtalar and Chopart joint, collapse and fragmentation of the talus are radiologically noted at advanced stages of the disease [23-25]. The awareness of the clinician, the collection of a thorough anamnesis, the use of modern diagnostic methods of multislice computed tomography (MSCT) and magnetic resonance imaging (MRI) assist in identifing changes in the ankle joint and determine the optimal treatment tactics. The true incidence and prevalence is still unknown, mainly due to late diagnosis and variation in the names of this pathology.

Classification

Despite the lack of a clear classification in the domestic literature, AOTB has a characteristic radiological picture depending on the stage of the disease. The most widely used classification is Ficat

[26], which has been revised over the years as a visual one. Diagnostic methods have improved and there is a better understanding of AOTB.

The current Ficat classification includes the following stages:

Stage 0 – preclinical

Stage I – preradiographic

Stage II – pre-collapse: radiographic changes, transition stage (flattening and sickle-shaped)

Stage III – collapse, fragmentation of talus but uninvolved adjacent joints

Stage IV – ankle osteoarthritis

Other classifications follow a similar pattern, describing the progression of the disease from the earliest manifestations to the final stage of collapse and fragmentation. Unfortunately, understanding of the AOTB is still incomplete.

Management of avascular osteonecrosis of the talus

The treatment of the condition is still a difficult task in modern traumatology and orthopedics; it may arise disappointment among clinicians and be a serious challenge for the surgeon. Fortunately, a number of advances in modern traumatology and orthopedics in understanding talus injuries, as well as the development of modern instrumentation, metal implants, and diagnostic methods, improve the results of treatment of this category of patients [27].

However, the result of complete destruction of the talus in AOTB and the existing options for surgical treatment in this situation are a difficult task, even in the best hands of the surgeon, due to the development of such adverse outcomes as an irreversible loss of motion in the functionally significant joints of the foot and ankle joint, a high risk of nonunion, high frequency of residual deformities, the need for long periods of immobilization of the limb and the rehabilitation [28].

A natural question arises: how to overcome the existing shortcomings and improve the results of treatment of patients with AOTB in the early and late stages of the disease? Optimal treatment strategies do not have the advantage of a high level of evidence. Case series are often accompanied by combined treatment plans and bias in selecting patients for correct management.

The adoption of one or another treatment tactic must still be adapted to each specific situation.

Surgical techniques for managing initial stages of the talar avascular necrosis associated with local defects

With regard to the desire to reduce the trauma due to surgical intervention, as well as in the historical aspect, the authors proposed a large number of non-radical methods. Such methods are debridement, multidirectional osteoperforation, microfracturing, which have been used since the middle of the 20th century [29]. All these methods are based on the idea of violating the integrity of the bone so that the elements of the bone marrow, pluripotent cells of the bone marrow and other elements of regeneration gain access from the depth of the spongy layer of the bone to the area of the talus defect. Also, the idea was to stimulate the bone marrow of the talus.

Today, the microfracture method has been still used [30] in cases of primary symptomatic local AOTB zones up to 10 mm in diameter.

However, the effectiveness of these operations is limited, as evidenced by the reports of a number of authors about the presence of fibrous tissue or fibrous cartilage in the area of the talus defect, progression of aseptic necrosis detected by control arthroscopy [31]. Of course, the newly formed tissue is inferior in its mechanical properties to hyaline cartilage and cannot withstand the previous loads, has the property of increased wear, and accelerates the development of deforming osteoarthritis of the ankle joint.

At the initial stages of the disease, in the presence of a defect in the talus, organ salvage operations, including osteochondroplasty of the defect with the use of a bone and cartilage graft, have proven themselves well [23, 32, 33]. This method has the advantage of replacing the lost cartilaginous surface with its own bone and cartilage tissue, prolonging the function of the ankle joint. Current literature reports sufficient evidence for the use of osteochondral autografts [34-43].

The negative side of the method is the limited production of plastic material, painful donor site syndrome, the difficulty in contouring the graft with the contour of the talus.

However, the course of AOTB of the talus block in the early stages tends to progression of the degenerative process resulting in the terminal stage of deforming arthrosis of the ankle joint, when the body of the talus is completely affected by necrosis and collapse, and sometimes with complete destruction of its structure and associated deformity.

Surgical techniques for managing late stages of the talar avascular necrosis associated with total lesion, collapse, fragmentation of the talar body

The literature describes the results of the use of allografts for the reconstruction of damaged articular surfaces and the filling large osteochondral defects. Appropriately sized and shaped allografts have been used to reconstruct the anatomy of the talus. Allograft implantation usually requires ankle osteotomy [44-46].

For the subsequent fixation of the graft, it is necessary to use various structures and internal fixators such as screws and biodegradable pins of small sizes.

The shortcoming of this method is the long period of consolidation and the high risk of allograft rejection. A number of authors note the difficulties in selecting the size of the allograft, taking into account the individual characteristics of the talus block in the recipient. In some countries, allotransplantation is prohibited for ethical reasons [41, 47-49].

Until now, astragalectomy, hindfoot arthrodesis (hereinafter HFA), pantalar arthrodesis of the foot are recommended in cases of AOTB [50]. The term pantalar arthrodesis was introduced in 1911 by Lorthior J who used this designation to generalize the joints of the hindfoot (ankle, subtalar, talo-navicular, calcaneocuboid joints), which were arthrodesised surgically in order to correct equinovarus deformity of the foot, thereby performing pantalar arthrodesis [51].

Pantalar arthrodesis of the foot and HFA are considered by many clinicians to be a salvage procedure. Typical indications include post-traumatic osteoarthritis of the ankle and hindfoot, rheumatoid arthritis, neurological dysfunction of the lower extremity, foot and ankle. This surgical operation is complex; its goal is to restore the functional and anatomically plantigrade position of the foot, while the hind foot should be slightly in a valgus position. Osteotomy of the forefoot and fibula is frequently required to correct deformities of the forefoot and hindfoot in the coronal plane.

Despite its advantages, this type of surgical intervention has significant drawbacks: the complexity of the procedure, frequent complications such as impaired bone fusion, residual varus/valgus deformities of the hindfoot, and fatigue fractures of adjacent bones [52]. The development and progression of deforming osteoarthrosis in neighboring joints (Chopart, Lisfranc, metatarsophalangeal joints) is a common complication, which, according to different authors, reaches up to 58 % of patients after 21 years of follow-up [53]. Nonunion and progression of AOTB have also been reported. Graves et al. [54] and Beischer et al. [55] noted that 28 to 33 % of their patients experienced difficulty by walking (lameness) after HFA and pantalar arthrodesis despite successful bone fusion. All this leads to pronounced functional limitations and deformities that are incompatible with the high level of physical activity of a modern patient [56, 57]. The authors proposed to consider this type of surgical intervention only as a rescue operation.

Ankle joint arthroplasty with standard designs of endoprosthesis

AOTB involving more than one third of the talus is an absolute contraindication for ankle replacement [58, 59, 60, 61]. AOTB less than one third is a relative contraindication, and the use of standard commonly available components increases the risk of significant subsidence (collapse) and decrease in the density of the talus and development of subsequent instability of the talar component. In order to reduce the risk of progression of collapse of the remaining part of the talus, special revision designs of ankle joint implants, such as Inbone 2, have been developed [44, 62].

Undoubtedly, modern revision designs of ankle joint endoprostheses allow expanding the indications for surgical treatment of patients with AOTB. However, the high risk of progression of the pathological process, the minimum amount of remaining bone under the talar component contributes to the development of instability of the talar component and directly affects the survival of the ankle joint endoprosthesis. A potential solution to the problem of surgical treatment of patients with avascular necrosis of the talus and preservation of biomechanics in the ankle joint is the creation of customized designs of the talus implants. According to the literature, personalized total talar implants show promising long-term results [63–68].

Historical aspects of talar endoprosthesis application

In recent years, there have been significant changes in the field of artificial bone replacement materials and bone products, such as calcium phosphate or hydroxyapatite, but it is still not clear whether the plasty of a total and subtotal TB defect in AOTB provides sufficient strength and reliability with a large amount of artificial bone. A noteworthy fact: in the early 70s, this technology originated in Japan in order to facilitate the tea ceremony in patients with severe crusarthrosis. The talus endoprosthesis (hereinafter referred to as ETB) was first mentioned in 1974 [66]. Harnroongroj et al. presented the first generation of stainless steel ETBs [67]. Th ETB was developed using slit scanography [69], involved arthroplasty of the body of the talus with partial preservation of the neck of the talus, and was implanted in sixteen patients between 1974 and 1990. The postoperative mean score, according to the AOFAS (Foot & Ankle Society ankle-hindfoot scoring system) [70, 71], was > 75 points. The first generation implant had a stem on the anterior surface of the structure intended for fixation in the TB neck (Fig. 1)

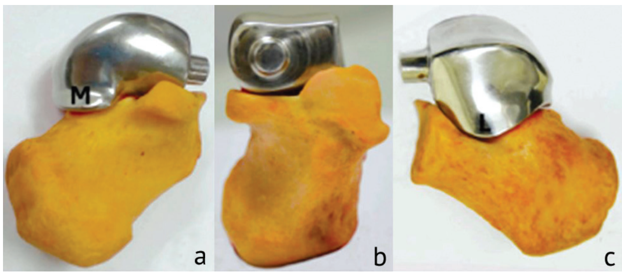

Fig. 1 Photo showing the final version of the first generation talus implant. The view is shown from the medial (*a*), anterior (*b*) and lateral (*c*) sides of the prosthesis, the lower part of which is fixed on the calcaneus [67]

The authors in their work described the results of applying this ETB design for 16 years. It was noted that the congruence of the ETC with the tibia and with the posterior calcaneal facet was good in all cases, except for one patient, in whom the diameter of the curvature of the posterior facet of the prosthesis was less than the diameter of the posterior calcaneal facet. That patient had persistent pain and swelling in the ankle area, and radiographs showed erosion of the posterior facet of the calcaneus (Fig. 2).

Fig. 2 Lateral radiograph shows erosion of the posterior facet of the calcaneus under the first generation implant components of the talus body eight months after implant placement. The first-generation talus implant destroyed the articular surface of the distal tibia, which led to varus deformity of the prosthesis [67]

In four patients, the authors described mild swelling of the ankle joint and temporary mild pain in the hindfoot during walking. The pain stopped after four to five months, and the swelling decreased within three months. The authors revealed wound infection, wound necrosis, neurovascular damage, or impaired function of the posterior tibial nerve and flexor hallucis longus tendon in none of the patients. On radiographs, the authors did not detect subchondral bone sclerosis or uneven articular spaces of the ankle joint or middle tarsal joint, or the posterior facet of the ankle joint and calcaneus, except in one patient. Three patients who were examined five years after the operation had a satisfactory result. Failure occurred in one patient eight months after implantation. The prosthesis was removed and tibio-talar arthrodesis was performed.

In 1999, Taniguchi et al. described the use of the first-generation ceramic ETB in 22 patients in the period from 1999 to 2006. [72]. Unlike their colleagues, the authors used alumina ceramics as a material of their implant, and also used computed tomography data. The implant was of two variants: with a stem (Fig. 3 a) and without a stem (Fig. 3 b), provided for the preservation of the head of the talus.

The mean follow-up period was 96 months. In all patients, a year after the operation, resorption and necrosis of the remnants of the talar neck were noted, leading to instability of the ETB components It served as a prerequisite for the development of the second type of ETB. The authors concluded that talar body arthroplasty cannot be recommended for patients with AOTB, at least according to their data, 50 % of patients will have a satisfactory result, and the remaining half of the patients will have a poor one. Currently, it is recommended to use a total talar endoprosthesis in patients with AOTB made of alumina ceramics. The authors demonstrated the use of the second generation ETB in a 74-year-old woman (Fig. 4 a, b).

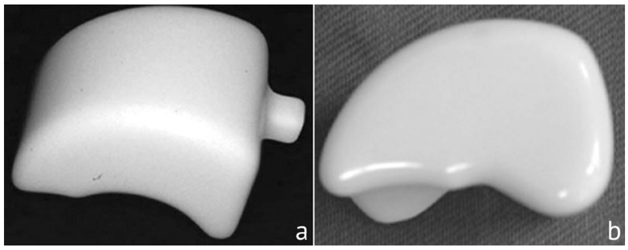

Fig. 3 The photographs show two types of ceramic implant of the talar body. The first generation prosthesis (a) has a stem for the neck of the talus, while the second generation prosthesis (b) does not [72]

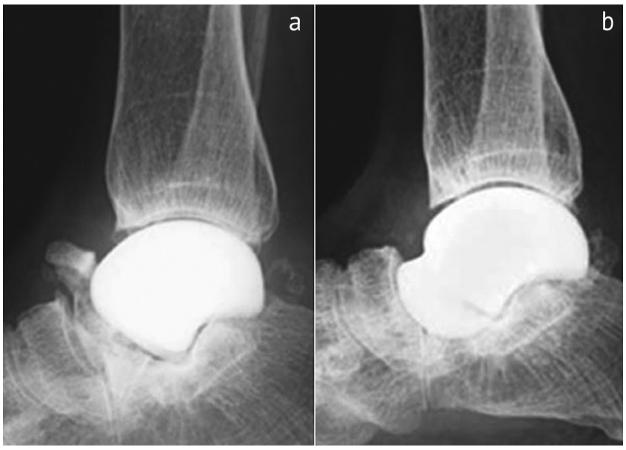

Fig. 4 Radiographs of a 74-year-old woman with avascular osteonecrosis of the talus treated with a first-generation endoprosthesis: a 1.5 years after surgery, the image shows the remaining necrotic talus neck and head fracture due to loosening and subsidence between the components of the endoprosthesis and neck of the talus; b after revision with the use of a second-generation talar endoprosthesis, a total endoprosthesis [72]

Until now, there is no unified concept among orthopedic traumatologists regarding the fixation of a customized TB implant to the subtalar and talo-navicular joints. The authors are divided in their opinions, some are in favor of the mobility and anatomical congruence of the implant to the surrounding articular surfaces, others are in favor of its partial stabilization in such joints as the talonavicular and subtalar. In 2017, Sebastien Ruatti et al. [73] from the University Hospital of Grenoble, France, reported a case of complete open traumatic dislocation of the talus in a 51-year-old patient without neurovascular complications who was treated with a customized talar endoprosthesis (Fig. 5).

The authors applied a two-stage treatment strategy; the first stage was surgical debridement of the wound, necrectomy, to stabilize the free space in the ankle joint and prevent retraction, a cement antibacterial spacer was placed adjacent to the articular surfaces of the tibia, scaphoid, and calcaneus (Fig. 6).

Fig. 5 Preoperative radiographs showing complete absence of the talus [73]

Fig. 6 Postoperative control radiograph showing the location of the spacer with the antibiotic in the tibiotal space [73]

Given the damage to the cartilage from the calcaneal facet of the subtalar joint, the authors decided to develop a customized talus implant made of a cobalt-chromium alloy with the possibility of direct fixation to the calcaneus with screws to enhance the osseointegration of the implant with the calcaneus. The surface of the endoprosthesis from the side of the calcaneus was additionally coated with hydroxyapatite, the surfaces of the endoprosthesis of the TB in the talonavicular and talotibial joints were polished (Fig. 7 a).

The second stage of surgical treatment consisted in the implantation of a customized TB prosthesis six months after the injury. The authors evaluated the radiographic results two years after the operation. It was rated as very good: there were no signs of osteolysis and instability of the TB implant on the control radiographs (Fig. 7 b). During the two-year follow-up period, the authors demonstrated preliminary, rather encouraging results, a good functional activity of the patient, assessed by the AOFAS scale, which showed an increase in scores from 11 to 77 out of 100.

Since 2005, there has been an improvement in the technologies used to create ETB, there has been a "rapid" growth in implantations in the period from 2005 to the present. Scientists Shnol et al. (Binghamton, NY, USA) published a scientific article in 2018 demonstrating the prospects for 3D printing of a customized TB implant in the treatment of progressive osteoarthritis of the ankle joint, avascular osteonecrosis and osteomyelitis [74]. West et al. published a literature review in 2020 on a case series of previously published results on the use of customized talar endoprosthesis designs. The authors analyzed the results of scientific publications in the period 2010-2020 onthe implantation of the TB endoprostheses, bringing all the data into a table (Table 1). The table shows the number of ETB implantations performed by the authors over the specified period, the main complications, data on the material used in the creation of the TB implant, the observation period, and the results of the design use [75].

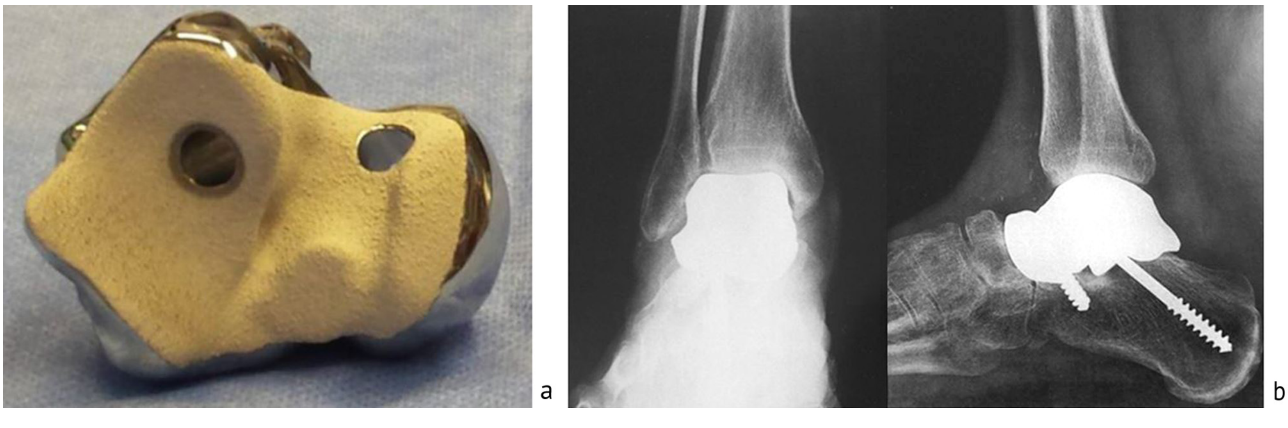

Fig. 7 Talus implant, ventral view, hydroxyapatite coating used for subtalar arthrodesis is visible on the caudal surface of the implant (*a*) [73]; *b* control radiographs 2 years after the operation

Table 1

Review of talus arthroplasty studies, implantation results presented from 2010 to 2020 [75]

Author	Number of implantations	Etiology	Implant type	Follow-up	Radiological findings	VAS	AOFAS	Functional status
Ando, 2016	1	AOTB	TBE alumina ceramics	2 years	Stable implant	–	90 (45)	No pain when walking, no need for an orthosis
Angthong, 2014	1	Extrusion, talar dislocation	TBE stainless steel 316L	4.6 months	Stable implant	–	–	Life activities without means of walking support
Fang, 2018	1	TB sarcoma	Titanium base and TBE UHMWPE	6 months	Stable implant	–	91 (18)	Life activities without means of walking support
Gadkari, 2013	1	Extrusion, talar dislocation	TBE made of cobalt-chromium alloy, porous coating on extra-articular surfaces	11 years	Mild plantar bending of the prosthesis, minimal spreading of osteophytes	–	75	intermittent mild pain, ability to walk on uneven terrain
Hamroongroj, 2014	33	AOTB, trauma, TB tumour	TBE stainless steel 316L (first generation)	from 10 to 20 years (n = 8) from 20 to 30 years (n = 11) from 30 to 36 years (n = 9)	Early failures including erosion, subsidence, fracture, osteonecrosis of the head/neck of the talus; 25 patients showed good survival. All patients had hypertrophic ossification within 10 years	–	78 (at 10 to 20 years) 76 (at 20 to 30 years) 76 (at 30 to 36 years)	out of 28 individuals available at the final follow-up, 20 were able to walk without pain for at least 1 hour (the remaining 8 were limited in movement due to comorbidities)
Katsui, 2020	6	Severe TB fractures	TBE ceramics	2 to 7 years	Progression of osteoarthritis in 2 patients who required revision and implantation of the tibial component of the ankle endoprosthesis	–	average 78.8	three returned to sports, two reported limited ankle range of motion
Regauer, 2017	1	Cadaveric study	TBE stainless steel 316L in combination with tibial component STAR and holes for fixation of the deltoid, anterior talofibular and interosseous tibial ligaments	No data	No data	–	–	–
Ruatti, 2017	1	Extrusion, talar dislocation	TBE made of cobalt-chromium alloy with hydroxyapatite coating on the caudal surface	2 years	No loosening, cystic formations no implant migration	–	77 (66)	
Scott, 2019	15	AOTB	TBE cobalt-chromium alloy	1year	Presevation of centering between the tibia and ETB, talus inclination angle and Meary's angle on postoperative radiographs	3.6 (3.4)	–	return to cycling and hiking improvement in daily life activities and quality of life compared to the preoperative state
Taniguchi, 2012	22	AOTB	8 TBE fist generation from alumina ceramics and a stem 14 TBE second generation from alumina ceramics without stem	8.2 years	Weakening around the ETB shaft and necrosis of the remnant head of the talus in all first generation implants. Migration between native talus and ETB body in 50 % of second generation implants	–	1st generation 80 (33.4) 2nd generation 81.1 (30.7)	50 % good or excellent results in the 1st generation, 57 % good or excellent results in the 2nd generation
Taniguchi, 2015	55	AOTB	TBE alumina ceramics	4.4 years	Sclerosis in the surrounding tissues	–	–	all returned to daily activities without walking aids
Tonogai, 2017	2	AOTB	TBE alumina ceramics	1.5 years	Well positioned implants, no loosening or migration	0 (8.5)	–	no pain with movement and no need for assistance with walking
Tracey, 2018	14	AOTB	Nickel-plated cobalt-chrome TBE	21 weeks	Significant increase in the talus height and reduction in the talus inclination after the operation	–	–	–
Tsukamoto, 2010	1	Falure of total ankle arthroplasty	TBE alumina ceramics	2 years	Stable implant, no loosening	–	–	no pain by walking, no need for an orthosis

Notes: AOTB – avascular necrosis of the talar bone; AOFAS – American Orthopaedic Foot and Ankle Society Hind Foot; UHMWPE – ultra-high molecular weight polyethylene; VAS – Visual Analogue Scale; TB – talar bone; TBE – talar bone endoprosthesis

Custom-made 3D printed ETBs have been successfully used as a functional alternative to HFA or foot amputation in cases of severe fracture or loss of the talus. Current designs are made from alumina ceramics, cobalt-chromium, stainless steel, titanium, or a combination of metals.

The severity and prevalence of damage to the body of the talus and ankle joint often does not allow for ankle arthroplasty. Fragmentation, the presence of huge cysts, collapse of the body and other lesions are the causes of this phenomenon. The in-depth assessment of the state of the ankle joint often reveals gross disfiguring osteoarthritis of the tibial pylon, which completely excludes the support of the talus implant on it. A number of authors propose modern options for solving this problem, namely, the use of the tibial component of the ankle joint endoprosthesis to restore the support of the tibial pylon to install the implant in the anatomical position and create a mobile link with the tibia. In the literature, references to combined arthroplasty of the talus in combination with the tibial component and the liner of the ankle joint endoprosthesis are quite rare (Fig. 8) [76].

The search for the ideal material for ETB is still ongoing. Most authors use alumina ceramics to design ETB. The scientific literature analysis reveals that ceramic materials, such as aluminum oxide (Al_2O_3), cause insignificant osteolysis due to a low coefficient of friction and a decrease in the formation of wear products [77, 78, 79].

This, along with high hardness, suitable compressive strength, and chemical stability under physiological conditions, has made it the material of choice for orthopedic prostheses (such as alumina-on-alumina hip implants). Ceramics based on Al_2O_3 (ATZ) is quite brittle and prone to cracking, which, in turn, can affect the survival of the TB implant [80].

Also, the production of ATZ products requires the use of expensive equipment; to achieve high mechanical parameters, it is necessary to use a hot isostatic press (HIP). Additional costs and complexity of post-processing are due to the high hardness of the material.

In domestic practice, an ETB implant made of composite zirconium ceramics was used. Literature analysis has shown that ceramics based on ZrO_2 (Y-TZP) has excellent physical and mechanical characteristics that meet all the needs in the production of endoprostheses, and surpasses ATZ ceramics in some parameters. One of the few shortcomings of Y-TZP is the tendency to strength properties degradation under the influence of external factors, due to the tetragonal-monoclinic phase transition. The most intensive degradation occurs in a humid environment at elevated temperatures and pressures. However, even with the presence of 75 % m-phase, the mechanical properties and the probability of failure were not increased, which may indicate the durability of the material used [81].

Another author published the result of surgical treatment of a patient with avascular osteonecrosis of the talus, deforming post-traumatic osteoarthritis of the ankle, subtalar and talo-navicular joints with post-traumatic tibiofibular diastasis using ZrO_2 ceramic ETB in combination with the tibial component of the ankle endoprosthesis, 20 months after operations (Fig. 8) [76].

Since 2005, there has been an improvement in the technology used to develop ETBs, there has been a "rapid" growth of implantations in the period from 2005 to the present. At the same time, the effectiveness of total talus arthroplasty turned out to be so high that in our time the operation has been performed throughout the Asia-Pacific region and in economically developed countries.

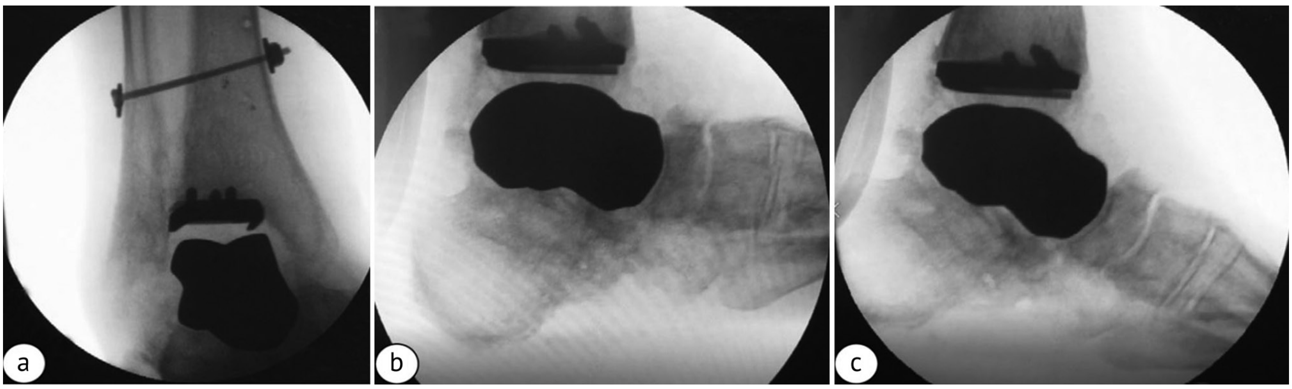

Fig. 8 Follow-up radiographs of the ankle joint 20 months after the operation: a AP radiograph, there is a good alignment of the metal implants, preservation of the contours of the ankle joint; b, c functional radiographs in the lateral view with dorsiflexion and plantar flexion of the foot: good position of the endoprosthesis components, total range of motion 28°

DISCUSSION

The question of the suitable material for TTA has been still debatable, and the questions of what material the implant should be made of, what qualities it should have, and what should be the position of clinicians in relation to the joints and ligaments surrounding the talus has not been resolved. Hybrid TTA implants have been proposed in combination with tibial components of ankle joint endoprostheses and fixation of the capsular-ligamentous apparatus of the TB with anchor fixators [82]. The evolution of the talus endoprosthesis has come a long way. Titanium-vanadium alloys, cobalt-chromium alloys, ceramics, and other materials were proposed; various designs for the talus have been proposed; and namely, implants of the trochlea with preservation of the head, total endoprostheses, including the navicular bone [83]. Due to the risk of instability of the endoprosthesis components and aseptic osteonecrosis of the remnants of the TB neck and head, TTA has been considered the optimal form, while the discussion about the materials of implant manufacture continues to this day. Disputes about how to implement the interaction of the endoprosthesis of the talus with the talonavicular and subtalar joints do not subside. An analysis of the literature showed that a number of authors proposed various screw fixation technologies, monolithic and adaptable stems for fixing these joints, and different methods of processing contact surfaces (polished, non-polished) [63, 84]. Nowadays, according to most authors, designing of a congruent surface with the listed joints and their precision polishing create compensation for the interaction at the endoprosthesis-talar bone-cartilage interface, which was confirmed by long-term clinical observations [73, 85, 86].

The understanding the nature of the disease such as AOTB may prevent unnecessary surgical interventions in patients in whom clinical and radiographic improvement is expected; or, on the contrary, it may prevent a long course of conservative treatment doomed to failure. Recognizing the consequences of the disease in case of inaction, clinical decisions are made, which are mainly based on the risks and benefits of surgical methods for treating patients with AOTB. Thus, in AOTB, the decision to initiate invasive procedures in a patient with minimal symptoms and intact talar structure requires a clear understanding of the fate of the untreated talus. The stage of the disease often reflects the progression of the pathological process and helps to make decisions about treatment tactics [87]. In AOTB, stages may be radiological or based on soft tissue changes, and may or may not be associated with clinical manifestations [88]. The revealed histological changes in the bone and cartilage tissue confirm the need for surgery to replace areas of the damaged bone and cartilage in the early stages and the use of massive bone auto/allografts, or TTA in the later stages of the disease.

CONCLUSION

Avascular osteonecrosis of the talus is a serious disabling disease which is polyetiological in nature. Pathogenetically, it is represented mainly by degenerative and necrotic lesions of the articular cartilage and the underlying bone substance of the talus trochlea. In the early stages it acts as a source of chronic inflammation localized in the ankle joint; the process leads to desquamation of the articular cartilage, formation of subcortical cysts, a pathological fracture of the talus and, as a result, to the development of severe, “disfiguring” deforming osteoarthritis of the ankle joint. A particular difficulty is the diagnosis of AOTB in the early stages. Planar radiography is unable to detect AOTB in many cases both at the stage of bone marrow edema and up to the stage of an impression fracture of the talus trochlea. Non-radical methods of surgical treatment of AOTB lead to an unacceptably large number of poor results. In the early stages of AOTB, radical surgical interventions have proven themselves well, which are a complete removal of the affected cartilage, intraosseous cysts, as well as the surrounding pathological focus of sclerotic bone and defect plasty. Treatment of patients with AOTB in the advanced stages of the disease is still a challenge for the clinician. Modern methods of surgical treatment are aimed at HFA with massive autopsy/alloplasty. With the accumulation of clinical material, we became convinced of the high need for a transition from HFA to modern sparing methods of treatment.

Our analysis of modern professional literature indicated the preference for the method of talus arthroplasty. The attractiveness of 3D printing of the talus lies in its anatomical coping and the possibility of creating various variations in the manufacture of the implant, such as combination with existing types of ankle joint endoprostheses, the possibility of applying a hydroxyapatite coating, forming holes for attaching ligaments. Implants can be constrained (subtalar arthrodesis) or unconstrained (polished surfaces facing the hindfoot joints).

The role of the talus is undoubted. The talus is unique in terms of its biomechanical and anatomical properties for the ankle and foot during walking. Just as the native talus communicates with adjacent structures via ligaments, yet remains free of muscle and tendon attachments, so can a custom-made talus implant meet the same anatomical requirements. The undoubted advantage of a custom-made talus implant is the restoration of congruence in the hindfoot joints in order to evenly distribute force and eliminate the source of pain in the ankle and foot. Custom-made 3D printed ETBs have been successfully used as a functional alternative to HFA or foot amputation in cases of severe fracture or loss of the talus. Modern designs are made of aluminium, zirconia ceramics, cobalt-chromium, stainless steel, titanium or a combination of metals.

The current technology of talus arthroplasty is scientifically substantiated, biomechanically confirmed and effective for the treatment of patients with AOTC and its consequences. While the demand for this technology has been growing all over the world, there is a constant improvement of tools, technologies and materials.

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