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Metabolic bone abnormalities underlying nonunion in revision foot surgeries

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Abstract

Introduction Revision foot surgery has increased in recent decades with the increasing surgical procedures. Nonunion is common after arthrodesis and osteotomies. From an economic perspective, revision surgery can be associated with greater length of disability imposing an additional financial burden on healthcare facilities. Impaired bone metabolism is one of the key factors leading to the risk of nonunion and a revision surgery.

The **aim** of the study was to determine the impact of metabolism bone abnormalities on the incidence of nonunion in revision foot and ankle surgery.

Material and methods A prospective study with retrospective control was conducted to compare two groups of patients aged 45 to 70 years who required revision foot surgery. The retrospective control group ($n = 36$) consisted of patients who had no bone metabolism assessment prior to revision foot surgery. The prospective group ($n = 42$) consisted of patients who underwent bone metabolism assessment preoperatively and subsequent correction if needed. Revision surgery was produced in the hindfoot and midfoot due to failed arthrodesis of the corresponding joints. AP and lateral weight-bearing radiographs of the foot, the Salzmann view and a CT scan of the feet were produced preoperatively.

Results The mean period from the initial consultation to surgical treatment was longer in the prospective group than in controls: (16.0 ± 4.0) weeks and (8.0 ± 1.7) weeks, respectively. There were no significant differences in the mean period of consolidation/ankylosis measuring (10.0 ± 2.2) weeks in controls and (8.0 ± 1.5) weeks in the prospective group. A statistically significant difference was found in the frequency of non-unions between the two groups showing 14 % ($n = 5$) in controls and 2.4 % ($n = 1$) in the prospective group.

Discussion The findings demonstrated clinical effectiveness of a comprehensive approach to revision foot surgery including optimization of biological factors for bone union. Protocol for preoperative assessment and correction of bone metabolism can significantly improve outcomes of revision procedures reducing the risk of recurrent nonunions and the need for revisions.

Conclusion The time from initial consultation to revision surgery was longer in the prospective group of patients with no statistically significant differences in the time to bone consolidation. The nonunion rate was higher in the control group with no diagnosis and correction of bone metabolism diagnostics performed, highlighting the importance in reducing the rate of revision foot and ankle surgeries.

Keywords: nonunion, revision surgery, bone metabolism, foot surgery, osteoporosis

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INTRODUCTION

Revision foot surgery has increased in recent decades with the increasing surgical procedures. Nonunion is common after arthrodesis and osteotomies [1, 2]. The nonunion rate with triple arthrodesis varies from 0 % to 29 % [3]. One of the key parameters leading to the risk of nonunion and the need for subsequent revision surgery is impaired bone metabolism, which can manifest itself in various forms [4]. Impaired bone metabolism is one of the key factors leading to the risk of nonunion and a revision surgery [4].

The preoperative protocol for revision surgery includes three sequential stages: diagnosis, planning and revision surgery. The diagnostic stage is initiated by a comprehensive clinical examination using instrumentation and laboratory methods. The primary goal of this stage is to identify the key factors that led to the failure of the previous surgical intervention [5].

There are mechanical and biological etiological factors of poor outcomes. Mechanical factors are associated with failure to adhere to surgical procedures, while biological factors are caused by pathophysiological changes in the patient's body and bone metabolism disorders.

The diagnosis of mechanical factors is based primarily on clinical and instrumentation examination. Most significant mechanical factors include instability of metal fixation, neglected alignment, underestimated role of ligaments, and, conversely, overreliance on soft tissue techniques.

A comprehensive and detailed examination is required for a patient to identify the biological factors that would necessitate a revision surgery. Biological factors are important with all mechanical conditions met, considering the age 65 and over, and concomitant somatic diseases. Involutional processes in the foot and an increased risk of osteoporosis are characteristic features of aging, more pronounced in females [6]. The aging foot [7] may develop a range of structural and functional changes and chronological age does not always correlate with the patient's functional status.

Although age is a significant risk factor for osteoporosis and other degenerative changes of the foot [8, 9], it should not be considered the sole or decisive criterion when planning treatment. A patient's functional status can vary significantly within a single age group, due to individual lifestyle factors, genetic factors, and comorbidities.

Therefore, a patient's age should be considered a warning factor requiring a thorough bone assessment and overall functional status, but not as an absolute contraindication to certain treatments. An individualized approach with a range of factors allows for optimized treatment strategies and improved outcomes in older patients.

Bone metabolism is a complex biochemical and biomechanical process regulated by numerous factors, some of which can be quantified and diagnosed. Foot deformities have a significant impact on bone metabolism, as explained by the mechanostat theory, also known as Wolff's law or Frost theory [10]. According to this theory, areas of the foot that are not subjected to adequate mechanical loading undergo adaptive changes, leading to a decrease in bone mineral density.

In addition to mechanical factors, biochemical disorders affect significantly bone metabolism. Vitamin D deficiency which plays a critical role in calcium homeostasis and bone mineralization is one of the key factors contributing to the development of osteoporosis [11].

A comprehensive assessment of bone metabolism and the detection of osteoporosis can be produced with the following laboratory tests [12]:

— *blood test*: complete blood count, coagulogram, blood biochemistry (glucose, creatinine, urea, total bilirubin, AST, ALT, total calcium, ionized calcium, phosphorus, alkaline phosphatase), blood vitamin D, osteocalcin;

— *urine test*: general urine analysis, dioxypyridinoline, urine calcium and phosphate (24 hours).

The results of these studies should be interpreted by specialists in bone metabolism (endocrinologists or the staff at hospitals for osteoporosis treatment). This is necessary for an accurate assessment of bone metabolism, the selection of optimal treatment strategies [13], and prioritizing correction of metabolic disorders over revision surgery. A comprehensive approach to diagnosis and correction of bone metabolism disorders allows us to optimize the management of patients with foot deformities and minimize the risk of postoperative complications.

The **aim** of the study was to determine the impact of metabolism bone abnormalities on the incidence of nonunion in revision foot and ankle surgery.

MATERIAL AND METHODS

A prospective study with retrospective control was conducted between 2018 and 2023 at the N.N. Priorov National Medical Research Center for Trauma and Orthopedics.

Inclusion criteria for the study:

— age from 18 to 75 years;

— the need for revision surgery for foot pathology.

Non-inclusion criteria:

— age under 18 and over 75 years;

— severe decompensated somatic diseases;

— congenital systemic bone diseases;

— infectious bone lesions (osteomyelitis);

— impaired mechanical principles of fixation.

The retrospective control group (n = 36) included patients who underwent revision foot surgery without prior bone metabolism assessment between 2018 and 2021. There were 83 % female (n = 30) and 17 % male (n = 6) patients. The mean age was 63.0±5.4 years. The prospective group (n = 42) included patients who underwent preoperative bone metabolism assessment and subsequent correction, if necessary, between 2021 and 2023. The group included 81 % female (n = 34) and 19 % male (n = 8) patients. The mean age was 61.0 ± 7.5 years.

The age of the patients ranged between 45 and 70 years. All patients included in the study lived normal lives and had no enhanced functional demands. There were no professional athletes or individuals whose daily activity levels significantly exceeded the average. The age limit (18–75 years) allowed for the inclusion of both relatively young patients without significant mobility limitations and older patients with moderate ankle impairments. None of them experienced extreme limitations in work or mobility. All patients underwent revision surgery on the hindfoot and midfoot due to failed consolidation after previous operations to correct acquired deformities.

Pathologies detected included:

— rigid flat-valgus deformity, not aggravated by severe decompensated somatic diseases;

— posttraumatic arthrosis of the ankle joint, subtalar joint and midfoot joints;

— acquired deformities resulting from aseptic necrosis of the foot bones (Müller – Weiss syndrome).

Osteosynthesis was performed using pre-modeled miniplates or cannulated screws, no external fixation used. Bone allografts were employed intraoperatively if needed. The surgical procedure was performed by a single surgical team of Department No. 13, the N.N. Priorov National Medical Research Center of Traumatology and Orthopedics. The distribution of the joints repaired with revision surgery is presented in Table 1.

Table 1

Distribution of patients by localization of the segment repaired with revision surgery

Localization of failed ankylosis	Control group (*n* = 36)		Prospective group (*n* = 42)	
	abs.	%	abs.	%
Talonavicular joint	6	17	8	19
Subtalar joint	15	42	15	36
Ankle joint	10	28	9	21
Two or more joints	5	14	10	24

With the bias towards revision surgeries for combined nonunions in various parts of the foot in the prospective group, the groups can be considered representative.

As part of the study, instrumentation examination of patients included:

— AP, lateral and Salzmann weight-bearing radiograps of the foot to assess the alignment of the foot;

— computed tomography of the contralateral limb to assess the bone condition, the volume of resection and bone grafting.

In the prospective group, laboratory tests were used to assess bone metabolism and subsequent correction parameters if neede (Table 2). Vitamin D deficiency (<30 ng/ml) was detected in 76 % of patients. Hypocalcemia and decreased osteocalcin indicate impaired bone remodeling processes. The parameters (e.g., vitamin D and calcium supplementation) were corrected to achieve target values, which might have contributed to the reduced nonunion rate in the second group. Table 2 presents the quantitative values of bone metabolism parameters in the prospective group.

Table 2

Bone metabolism measured in patients of the prospective group (*n* = 42)

Description	Average value ± SD	Reference values	Patients with deviations	
			abs.	%
Vitamin D (ng/ml)	25.0 ± 6.4*	30–100	32	76
Total calcium (mmol/l)	2.12 ± 0.15	2.15–2.55	19	45
Ionized calcium (mmol/L)	1.02 ± 0.08	1.12–1.32	22	52
Phosphorus (mmol/L)	0.87 ± 0.12*	0.81–1.45	10	24
Alkaline phosphatase (U/L)	98 ± 32	40–150	5	12
Osteocalcin (ng/ml)	14.5 ± 4.1*	11–43	13	31

The study assessed the time to achieve consolidation based on computed tomography results. Consolidation criteria included the presence of a "cortical bridge" and the formation of a trabecular bone pattern across the fracture line, which is a generally accepted approach.

The average time from the initial consultation to surgery was also assessed. This parameter is indirectly related to the economic costs of patient treatment, as increased disability reduces the cost-effectiveness of the model used. The nonunion rate as a key factor in comparison of the effectiveness of the approaches was assessed after revision surgery in the retrospective and prospective groups. The Pearson chi-square test was employed for statistical analysis due to its effectiveness and ease of use in assessing significant differences between groups.

RESULTS

The statistical analysis showed that the average time from the initial consultation to surgical treatment was longer in patients of the prospective group than in the controls measuring (16.0 ± 4.0) and (8.0 ± 1.7) weeks, respectively. The difference was caused by 3–4 weeks required for laboratory tests and subsequent interpretation in the prospective group. Appropriate conservative therapy aimed at correction of bone metabolism was administered for patients with metabolic disorders, with follow-up testing. With reference values recorded patients could undergo surgical treatment. In some cases, surgery could be performed alongside the therapy prescribed (for example, for isolated vitamin D deficiency) to reduce the waiting time for surgical intervention.

There were no statistically significant differences in average consolidation time that measured (10.0 ± 2.2) weeks in the prospective group and (8.0 ± 1.5) weeks in the control group. The phenomenon could be associated with the fact that of bone metabolism correction helps restore human biology rather than stimulates it. Consolidation time cannot be expected to reduce.

The incidence of nonunions was 14 % (n = 5) in the retrospective group and 2.4 % (n = 1) in the prospective group. The distribution of patients by location of nonunions after revision surgery is presented in Table 3.

Table 3

Localization of nonunions after revision surgery

Localization of failed ankylosis	Control group (n = 36)		Prospective group (n = 42)	
	abs.	%	abs.	%
Talonavicular joint	0	0	0	0
Subtalar joint	2	5.6	0	0
Ankle joint	2	5.6	0	0
Two or more joints	1	2.8	1	2.4
Total	5	14.0	1	2.4

The chi-square test revealed that the differences in nonunion rates between the control and prospective groups were not statistically significant at the 0.05 significance level. There was a trend toward a lower nonunion rate in the prospective group, which could be the subject of further study. Statistically significant differences are likely to be found with calculations in larger groups to allow for convincing conclusions about the effectiveness of the model used.

DISCUSSION

Literature review suggests that nonunion is a statistically significant complication in revision foot surgery.

Chrea et al. reported postoperative complications in foot and ankle procedures affecting patient satisfaction with the outcomes regardless of preoperative expectations [14]. This effect persists even after full functional recovery.

Greer et al. reported nonunion rates after foot and ankle arthrodesis ranging between 0 % and 36 % with the mean of 10 % to 11 % [15]. Chraim et al. [16] reported 20 % of the nonunion rate after subtalar joint arthrodesis. Rao [17] reported 100 % of patients with nonunion after ankle arthrodesis having vitamin D deficiency. Controllable risk (vitamin D, smoking) and uncontrollable risk (diabetes) should be assessed when establishing the diagnosis of ankle nonunion after arthrodesis [17].

Cardoso et al. suggested that determining who is at risk of developing nonunion is essential to reducing nonunion rates and improving patient outcomes [18]. The authors identified several evidenced-based modifiable risk factors related to adverse outcomes after foot and ankle arthrodesis. Patient-related risk factors that can be improved before surgery include smoking cessation, good diabetic control (HbAc1 < 7 %) and vitamin D supplementation.< 7 %). The impact of smoking on the outcomes of foot and ankle surgeries is greater than that of other segments.

Nicotine reduces prostocyclin levels, leading to vasoconstriction and tissue hypoperfusion. There is evidence suggesting a link between smoking, low bone mineral density and delayed fracture healing. Diabetes mellitus also negatively impacts bone reparative capacity. Hyperglycemia and insulin deficiency lead to apoptosis of chondrocytes and osteoblasts, which can contribute to the development of nonunions after foot surgery. Poorly controlled glucose levels in diabetic patients lead to a twofold increase in the risk of postoperative nonunions. Vitamin D levels are low in 70 % of patients with musculoskeletal disorders and very low in 22 % of patients undergoing elective foot and ankle procedures. Low vitamin D levels decrease intestinal absorption of calcium and phosphate, causing an increase in parathyroid hormone, which leads to increased osteoclast activity and decreased bone density [18].

Anciano et al. reported vitamin D deficiency in failed foot and ankle arthrodesis. A total of 13 patients who developed a nonunion agreed to have vitamin D level obtained, and 11 of 13 patients had a low vitamin D level (mean = 14.6 ng/mL, range = 9–24 ng/mL). Five patients underwent revision arthrodesis after normalization of vitamin D levels, and four out of five patients went on to successful union. The authors concluded that hypovitaminosis D may be a modifiable risk factor for nonunion after major foot and ankle arthrodesis. The authors concluded that hypovitaminosis D may be a modifiable risk factor for nonunion following a major foot and ankle arthrodesis procedure. Orthopedic surgeons should consider vitamin D screening and supplementation in patients undergoing elective arthrodesis procedures [19].

Combined vitamins D3 and K2 therapy plays a central role in calcium metabolism. Vitamin D3 improves calcium absorption, while vitamin K2 activates osteocalcin and matrix Gla protein, which promotes targeted bone mineralization and reduces the risk of soft tissue calcification. Although we did not use such preparations in our series, their inclusion in the preoperative preparation protocol could improve calcium metabolism in osteoporotic patients or resistance to vitamin D monotherapy [20]. It can be concluded that modifiable risk factors, including impaired bone metabolism, increase the risk of nonunion during foot and ankle surgery, and early diagnosis and bone metabolism regulation can reduce the incidence of nonunion and re-operation rate [21].

No measurements of hormonal levels (e.g., parathyroid hormone, testosterone, and estrogen levels) in the series, which is a limitation. Given the known impact of endocrine disorders on bone metabolism, further study of this relationship would be practical. Hormonal profile screening

in all patients prior to revision surgery may be challenging due to economic and organizational constraints. It can be performed selectively, for example, in patients with refractory mineral metabolism disorders or suspected endocrinopathies. Assessment of bone metabolism is essential for candidates for foot revision surgery and further studies are scheduled for better understanding of the correlation between bone metabolism and surgical outcomes.

CONCLUSION

The time from initial consultation to revision surgery was expectedly longer in the prospective group of patients due to the time required for bone metabolism assessment and regulation. There was no statistically significant difference in the time to bone consolidation between the groups. The nonunion rate was higher in the controls who did not undergo diagnosis or regulation of bone metabolism. Timely diagnosis and treatment can help reduce the incidence of revision surgeries related to nonunion due to impaired bone metabolism.

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