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Bone mineral status in patients with chronic spinal cord injuries (5 and more years after the trauma)

Abstract. Background. Improved social adaptation and increased life expectancy of persons with complete spinal cord injury bring into focus the late complications of spinal cord injuries (SCI) including osteoporosis and fragility fractures due to SCI-induced osteoporosis. Aim of the study is to evaluate the bone mineral status in patients with chronic spinal cord injury of 5 years and over. **Materials and methods.** 73 subjects who suffered from complete spinal cord injury with tetra- or paraplegia and 57 healthy persons were examined. **Results and conclusion.** SCI patients demonstrated significantly lower parameters of bone mineral status compared with subjects of the control group. In patients with SCI which occurred before peak bone mass formation, bone mineral density was significantly worse than in subjects who were subsequently injured and became a high risk group for fractures as a result.

Keywords: spinal cord injury; osteoporosis; tetraplegia; paraplegia; ultrasound densitometry

Introduction

Improved social adaptation and increased life expectancy of persons with complete spinal cord injury bring into focus the late complications of spinal cord injuries (SCI) including osteoporosis and fragility fractures due to SCI-induced osteoporosis. Such complications have been studied since the first half of the 20th century, but no common approach to its diagnosis and treatment has been developed. Most of studies are devoted to bone changes in the first days, weeks and months after the injury, when intense bone resorption starts. During the first years after a complete spinal cord injury, rapid loss of bone mass develops, which reaches 20%-50% of bone mineral density (BMD) of paralyzed limbs [7]. Demineralization of trabecular bone tissue occurs faster than of the cortical one, due to its higher metabolic activity [7]. There is no common opinion about the duration of the period of increased resorption after SCI. Some studies have shown that bone loss is decreasing over 3-5 years after the injury [8]. Other studies showed continued bone loss in later stages of post-traumatic period [2, 3]. The intensity and duration of bone loss are caused by many factors, which depend not only on the characteristics of injury but also on parameters of many organs and systems of the patient. The leading role has the level of spinal cord injury and mobility of the patient. Verticalization was reported to prevent progressive bone loss. But the role of factors affecting bone tissue in patients with complete spinal cord injury has not been determined so far.

Objective of the study is to evaluate the bone mineral status in patients with a spinal cord injury history of 5 and more years.

Materials and methods

In cooperation with the Association of Disabled Persons with Spinal Cord Injuries, 73 people who suffered from spinal trauma with complete spinal cord injury, tetra- or paraplegia were examined. Among them 38 were men, their average age being 40.1 ± 12.2 years, 35 were women, their average age being 41.3 ± 11.3 years, the duration of the post-traumatic period is 15.7 ± 10.6 years. Patient examination was conducted in conjunction with the Association of Disabled Persons with Spinal Cord Injuries. Examined patients lead an active lifestyle that excludes the impact of prolonged bed regime. Volunteers accompanying subject with SCI were also examined as a comparison group. Volunteers were recruited as a rule from among the patients' relatives: parents, children, spouses, which could partially reduce the impact of other factors affecting bone tissue, including eating habits, living environment, and genetic factors.

Bone status was determined by ultrasound (US) densitometry of the calcaneal bone using quantitative ultrasonometer Sahara (Hologic Inc., model 04874, 2008). Ultrasound densitometry assessed: speed of sound (SOS, m/s); broadband ultrasound attenuation (BUA, dB/MHz); stiffness index (SI, %), calculated by computer on the basis of SOS and BUA parameters; extrapolated

mineral density of calcaneal bone; T-score (patient's SI difference from the index of conventionally healthy adults aged 20 years, is expressed in standard deviations); Z-index (patient's SI difference from the index of conventionally healthy adults of the same age is expressed in standard deviations).

The statistical analysis was performed using Statistica 10 software. Results are presented as mean values ($M \pm SE$). The difference in parameters between the groups was de-

finied using one-way analysis of variance ANOVA. Inter-group differences were evaluated by Scheff test. The difference in parameters is considered significant at $p < 0.05$.

Results

The results of ultrasound densitometry in patients with spinal cord injuries demonstrated significantly lower parameters of bone density compared with those in the control group (Table 2).

Table 1. Characteristics of examined SCI patients and subjects of the control group

Parameter	Main group, n = 73		Control group, n = 57		P	
	men, n = 38	women, n = 35	men, n = 21	women, n = 36	men	women
Age, years	40.1 ± 12.2	41.3 ± 11.3	39.7 ± 13.8	46.8 ± 12.2	0.91	0.06
Height, cm	178.6 ± 7.2	164.1 ± 5.6	177.3 ± 5.6	163.2 ± 5.8	0.48	0.52
Weight, kg	72.9 ± 9.1	59.2 ± 5.7	71.2 ± 10.6	62.3 ± 9.6	0.51	0.11
BMI, kg/cm ²	22.9 ± 2.9	22.1 ± 2.2	22.7 ± 3.3	23.5 ± 4.0	0.77	0.01
Trauma age, years	23.6 ± 7.5	26.5 ± 8.3				
Trauma duration, years	16.5 ± 11.4	14.9 ± 6.6				
Trauma level, vertebrae	C ₄₋₆ = 9 Th ₂₋₁₂ = 19 L ₁ = 11	C ₆ = 1 Th ₄₋₁₂ = 22 L ₁ = 12				

Table 2. Bone mineral status of patients with spinal cord injuries and subjects of the control group

Parameter	Men		Women	
	Main group	Control group	Main group	Control group
T-score, SD	-3.2 ± 0.8*	-0.4 ± 0.8	-3.1 ± 0.5*	-0.6 ± 0.6
Z-index, SD	-2.7 ± 0.7*	0.4 ± 0.2	-2.9 ± 0.5*	-0.4 ± 0.6
Extrapolated BMD, g/cm ²	0.25 ± 0.08*	0.55 ± 0.10	0.24 ± 0.06*	0.51 ± 0.07
BUA, dB/MHz	40.5 ± 13.8*	78.7 ± 15.7	37.4 ± 12.7*	76.9 ± 11.3
SOS m/s	1477 ± 19*	1554 ± 26	1473 ± 25*	1542 ± 18

Note: * – $p < 0.05$, differences in parameters of the main and control groups.

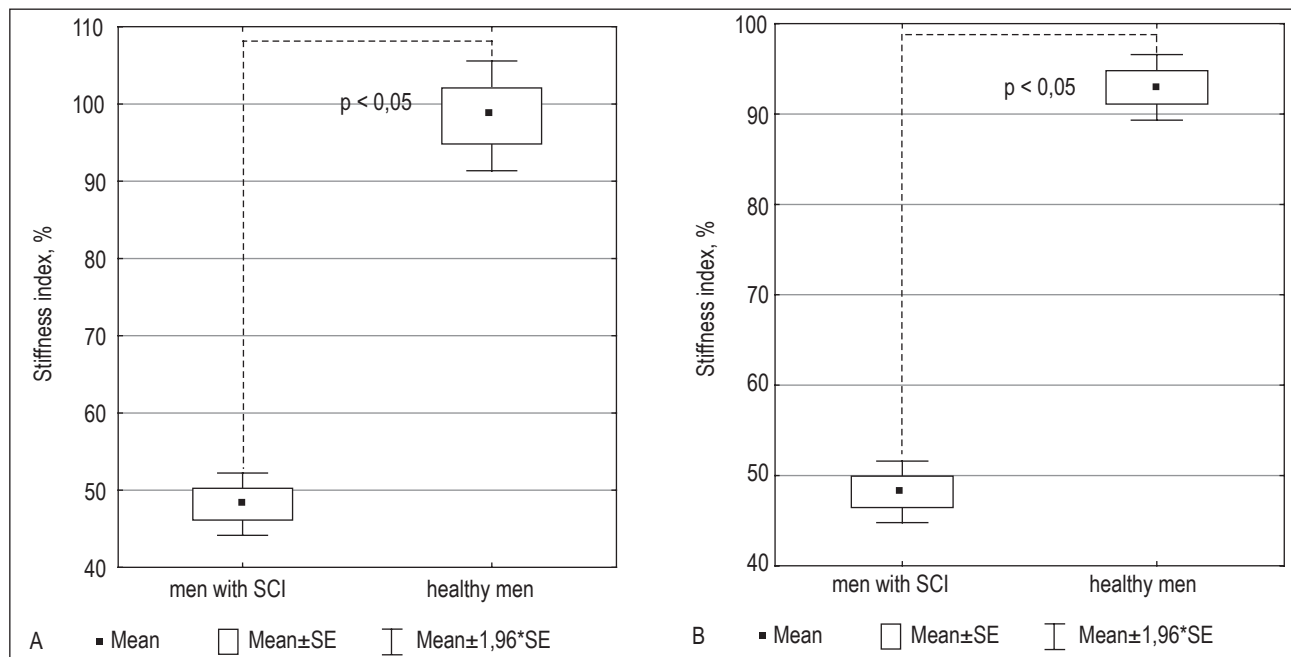


Fig. 1. Stiffness index in examined men (A) and women (B) of the main and control groups

Analysis of the data in Table 2 has shown no impact of gender on parameters of the bone mineral status ($p > 0.05$). Also, there was no significant influence of age, height, injury level and duration of disease on bone mineral parameters.

Significant moderate correlation between SI and body weight was obtained in men of the main group (Fig. 2). The women did not reveal any influence of anthropometric data on bone mineral status.

Bone mineral density was found to depend on the trauma age in men and women of reproductive age (Fig. 3 and 4).

It is known that a spinal trauma with complete spinal cord injury leads to intensive bone loss in the first years after the injury [5]. Further, the rate of loss is decreasing and the bone parameters are less dependent on the duration of post-traumatic period, but there is a proven relationship of osteoporosis risk and bone characteristics at the time of the injury [9].

Results of the study performed by Professor V. V. Povoznyuk in 1998 show that in the Ukrainian population women reach peak bone mass at the age of 23-24 years and men – at the age of 25-26 [1]. In present study, patients were divided into 2 subgroups according to their trauma age. A cutting-off point for men was 25 years and for women – 23 years of age.

In patients with the SCI that occurred before peak bone mass formation, the bone mineral status according to ultrasound densitometry was significantly worse than in the patients who had SCI at an age over 23 and 25 years, respectively (Table 3, Fig. 5).

Women did not show any difference in bone mineral status depending on the age of SCI onset, but after exclud-

ing postmenopausal women from both study groups, it was found that bone mineral density was significantly lower in women with trauma occurring at the age of 23 years and younger (Fig. 6). Significant difference in stiffness index

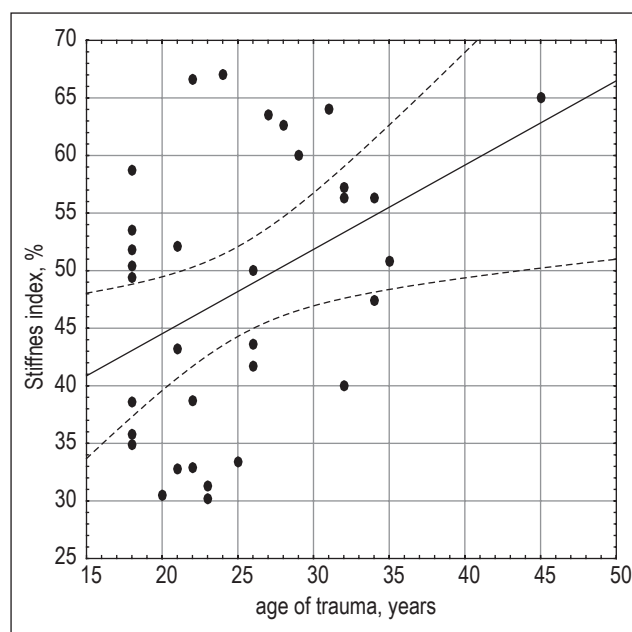


Fig. 3. Relationship of stiffness index and age of trauma in men of the main group.

Note. Relationship is described by the linear regression equation:

$$SI (\%) = 29.89 + 0.73 \cdot \text{trauma age (years)},$$

$$r = 0.41; p = 0.019; r^2 = 0.16$$

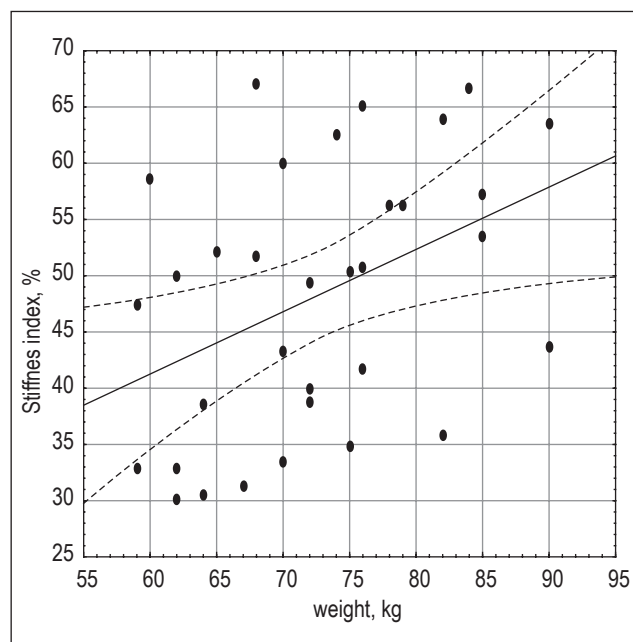


Fig. 2. Relationship between stiffness index and body weight in men of the main group.

Note. Relationship is described by the linear regression equation:

$$SI (\%) = 8.01 + 0.55 \cdot \text{weight (kg)}; r = 0.41;$$

$$p = 0.017; r^2 = 0.17$$

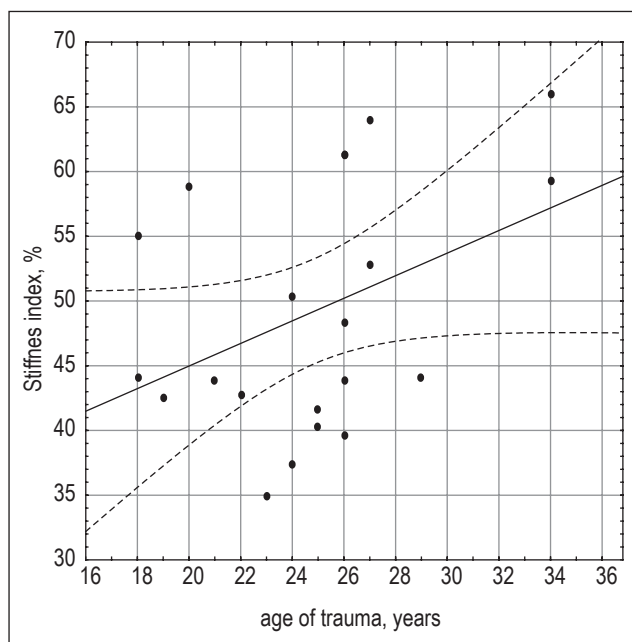


Fig. 4. Relationship of stiffness index and trauma age in women of reproductive age.

Note. Relationship is described by the linear regression equation:

$$SI (\%) = 25.74 + 0.87 \cdot \text{trauma age (years)},$$

$$r = 0.40; p = 0.048; r^2 = 0.16$$

Table 3. Characteristics of the main group patients depending on the age of the SCI onset.

Parameter	SCI patients before peak bone mass formation		SCI patients after peak bone mass formation		P	
	men, n = 19	women, n = 13	men, n = 15	women, n = 20	men	women
Age, years	36.4 ± 10.8	39.8 ± 11.3	43.8 ± 11.9	45.6 ± 10.3	0.06	0.06
BMI, kg/cm ²	22.4 ± 2.9	21.1 ± 1.7	23.1 ± 2.7	22.3 ± 2.4	0.51	0.15
Post-traumatic period duration, years	16.5 ± 7.5	15.3 ± 12.9	13.6 ± 9.1	14.4 ± 6.1	0.41	0.78

in women of reproductive age and postmenopausal women was not found because of the heterogeneity of the groups. In addition, the impact of menopause should be considered in certain groups of women, depending on the age of SCI onset before or after peak bone mass formation.

Among the examined subjects, 18 (24,6%) patients had hip fractures (11 patients) or tibia fractures (7 patients) due to low-energy trauma in the period after the spinal cord injury. 66% of them were the subjects who had got spinal cord injury before 25 years ($p = 0.001$). Other differences between the group of patients with fractures and without fractures were not detected.

Discussion

Increased bone resorption in SCI patients occurs very quickly after the injury and affects the bone mineral density of bones below the spinal cord injury level. According to the results of previous studies, in particular Bryson J. E. et al., 2009, patients with signs of complete spinal cord injury who had a fracture due to low-energy trauma, were diagnosed with a significant loss of bone mineral density in the distal femur (54%) and proximal tibia bone (73%), which occurred during the first 5-7 years after the injury [5]. The loss of bone tissue is greater in the distal section compared to the proximal one. The mentioned trend suggests that the level of loss at the calcaneal bone will be greater, also due

to the higher content of spongy bone in the calcaneal bone. The use of ultrasound densitometry of the calcaneal bone as a screening method in the diagnosis of osteoporosis is based on the close relationship of parameters to the vertebral bone and calcaneal bone. In SCI patients, this relationship is missed [4, 6]. After a complete spinal cord injury, the bone mineral density disorders depend on the level of the trauma. In parts of the skeleton located above the injury level, the bone mineral density decreases immediately after the injury, but gradually returns to baseline parameters and even increases with increased load, such as bone mineral density of upper extremities in patients with paraplegia. In the sections below the injury, with impaired innervation and reduced static loading, such as lower extremities, bone mineral density decreases progressively [6]. Thus, regardless of the injury level, the lumbar vertebrae and calcaneal bone manifest various conditions and changes in them are happening along the oppositelines. The most frequent localization of fractures in these patients and therefore an area of interest is the distal femur and proximal tibia. These areas consist mainly of spongy bone and are closer in composition to the calcaneal bone, therefore losing bone tissue in a similar way in the absence of axial load and adequate trophic effects.

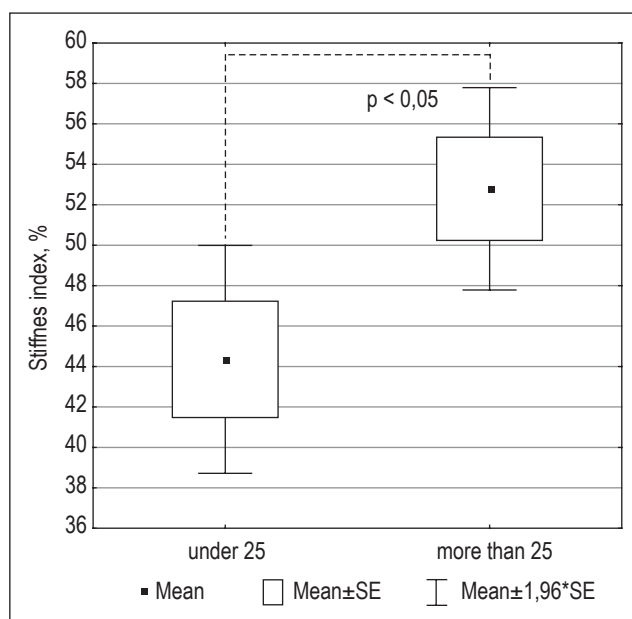


Fig. 5. Bone mineral status of men depending on the spinal cord injury age.

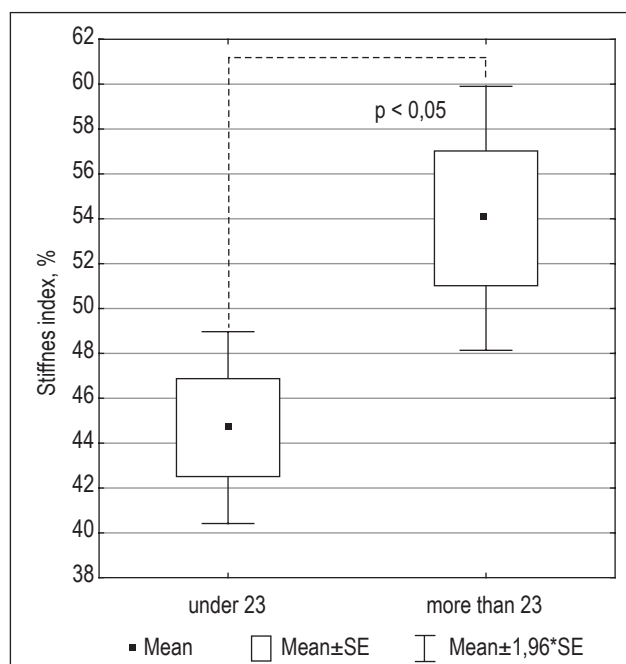


Fig. 6. Bone mineral status of reproductive age women with SCI depending on the age of trauma occurrence.

Inverse correlation was shown between the post-traumatic period duration and the number of proximal tibia trabeculae, which confirmed the continuing predominance of resorption processes in spongy bone. In parallel, thinning of the lower extremity long bones' cortical layer was taking place, but the loss of cortical layer occurred much more slowly than that of trabecular bone. Slow cortical layer thinning may explain the fact that the average period until the first fracture in SCI patients is 9 years after the injury [1]. Thus, correction of the structural-functional state of bone tissue as a means of fracture prevention has a large therapeutic window of 9 years. Among the leading risk factors for osteoporosis in SCI patients, along with severity of the injury and absence of axial loading in the post-traumatic period, there are low baseline values of mineral density [9]. This coincides with the results obtained in our study. Patients who had an injury before achieving peak bone mass have lower parameters of the bone mineral status and increased fracture risk. All patients with SCI in our study had a low bone mineral density (according to Z-score or T-score, depending on the age). According to the 2014 National Osteoporosis Foundation guidelines, SCI refers to the list of diseases and conditions that contribute to the development of osteoporosis and fractures, and therefore patients with SCI and low bone mineral density can be diagnosed with secondary osteoporosis. The prevalence of this condition among SCI patients encourages to continue the researches.

Conclusions

SCI with complete spinal cord injury leads to increased bone resorption with formation of secondary osteoporosis (according to the ultrasound densitometry of the calcaneal bone). The bone mineral status of patients with SCI which occurred before peak bone mass formation is significantly worse compared with subjects who had an already formed peak bone mass, and makes them a high risk group for fracture.

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Структурно-функціональний стан кісткової тканини в пацієнтів із травмою хребта та спинного мозку через 5 та більше років після травми

Резюме. Актуальність. Поліпшення соціальної адаптації та збільшення тривалості життя осіб із повним пошкодженням спинного мозку сприяло залученню уваги до пізніх ускладнень травми хребта і спинного мозку (ТХСМ), включаючи остеопороз і переломи внаслідок низькоенергетичної травми. **Мета дослідження** — оцінити структурно-функціональний стан кісткової тканини в пацієнтів із ТХСМ через 5 та більше років після травми. **Матеріали та методи.** Було обстежено 73 особи (38 чоловіків та 35 жінок) з тетра- або параплегією внаслідок ТХСМ та 57 практично здорових осіб. Ультразвукову денситометрію п'яtkової кістки проводили за допомогою кількісного кісткового ультрасонометра. **Результати.** Індекс міцності кісткової тканини (ІМ) був достовірно нижчим у па-

цієнтів основної групи й склав $51,4 \pm 11,8$ і $98,5 \pm 16,6$, $p < 0,05$, у чоловіків та $50,1 \pm 9,8$ і $92,9 \pm 11,1$, $p < 0,05$ у жінок. У випадку ТХСМ до досягнення піку кісткової маси ІМ кісткової тканини був вірогідно гіршим, ніж у пацієнтів з настанням травми після його досягнення. **Висновки.** ТХСМ призводить до формування вторинного остеопорозу. У пацієнтів із ТХСМ, яка настала до досягнення піку кісткової маси, структурно-функціональний стан кісткової тканини вірогідно гірший у порівнянні з пацієнтами відповідного віку та тривалості посттравматичного періоду, що відносить цю категорію хворих до групи високого ризику виникнення переломів.

Ключові слова: травма хребта та спинного мозку; остеопороз; тетраплегія; параплегія; ультразвукова денситометрія

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Структурно-функциональное состояние костной ткани у пациентов с травмой позвоночника и спинного мозга через 5 и более лет после травмы

Резюме. Актуальность. Улучшение социальной адаптации и увеличение продолжительности жизни лиц с полным повреждением спинного мозга способствовало привлечению внимания к поздним осложнениям травмы позвоночника и спинного мозга (ТПСМ), включая остеопороз и переломы вследствие низкоэнергетической травмы. **Цель исследования** – оценить структурно-функциональное состояние костной ткани у пациентов с ТПСМ через 5 и более лет после травмы. **Материалы и методы.** Было обследовано 73 человека (38 мужчин и 35 женщин) с тетрапаралегией вследствие ТПСМ и 57 практически здоровых лиц. Ультразвуковую денситометрию пяточной кости проводили с помощью количественного костного ультрасонометра. **Результаты.** Индекс прочности костной ткани (ИП) был достоверно ниже у пациентов основной группы и составил $51,4 \pm 11,8$

и $98,5 \pm 16,6$, $p < 0,05$, у мужчин и $50,1 \pm 9,8$ и $92,9 \pm 11,1$, $p < 0,05$ у женщин. В случае ТПСМ до достижения пика костной массы ИП костной ткани был достоверно меньше, чем у пациентов с наступлением травмы после его достижения. **Выводы.** ТПСМ приводит к формированию вторичного остеопороза. У пациентов с ТПСМ, произошедшей до достижения пика костной массы, структурно-функциональное состояние костной ткани достоверно хуже по сравнению с пациентами соответствующего возраста и продолжительности посттравматического периода, что относит эту категорию больных к группе высокого риска возникновения переломов.

Ключевые слова: травма позвоночника и спинного мозга; остеопороз; тетрапаралегия; паралегия; ультразвуковая денситометрия