

Clinical Study

# Metal concentrations in the blood and tissues after implantation of titanium growth guidance sliding instrumentation

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## Abstract

**BACKGROUND:** Growth guidance sliding treatment devices, such as Shilla (Medtronic, Minneapolis, MN USA) or LSZ-4D (CONMET, Moscow, Russia), used for the treatment of scoliosis in children who have high growth potential have unlocked fixtures that allow rods to slide during growth of the spine, which avoids periodical extensions. However, the probability of clinical complications associated with metallosis after implantation of such devices is poorly understood. The content of metal ions in the blood and tissues of pediatric patients treated for scoliosis using fusionless growth guidance sliding instrumentation has not yet been investigated.

**PURPOSE:** The aim of the present study was to measure the content of metal ions in the blood and tissues surrounding the implanted growth guidance sliding LSZ-4D devices made of titanium alloy (Ti6Al4V), and to identify the incidence of metallosis-associated clinical complications in some patients with these devices.

**STUDY DESIGN:** This is a one-center, case-control retrospective study.

**PATIENTS SAMPLE:** The study group included 25 patients with high growth potential (22 females, 3 males; average age at primary surgery for scoliosis treatment is 11.4±1.2 years old) who had sliding growth guidance instrumentation LSZ-4D (CONMET) implanted on 13 (range: 10–16) spine levels for 6±2 years. The LSZ-4D device was made from titanium alloy Ti6Al4V and consisted of two rectangular section rods and fixture elements. Locked fixtures were used on one spinal level, whereas the others were unlocked (sliding). The control group consisted of 13 patients (12 females and 1 male; 11±1.2 years old) without any implanted devices.

**OUTCOME MEASURES:** The content of Ti, Al, and V metal ions in the whole blood and tissues around the implanted device was measured. The incidences of metallosis-associated complications in the study group were recorded.

**METHODS:** Metal ion content was measured by the inductively coupled mass spectrometry method on quadrupolar NexION 300D (PerkinElmer Inc, Shelton, CT, USA).

**RESULTS:** Five of 25 patients in the study group developed metallosis-associated complications (two sinuses and three seroma in the lumbar part of the spine). Revisions were carried out in two of these patients. Ninety percent of the patients in the study group had increased content of Ti and V ions in the blood (2.8 and 4 times, respectively). Median content of Ti ions in soft tissues adjacent

FDA device/drug status: Not approved for this indication (spinal sliding instrumentation LSZ-4D [for early-onset scoliosis treatment]).

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The disclosure key can be found on the Table of Contents and at [www.TheSpineJournalOnline.com](http://www.TheSpineJournalOnline.com).

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to implanted sliding device was more than 1,500-fold higher than that of the control group. These levels are much higher than previously reported for spinal instrumentation.

**CONCLUSIONS:** Increased content of Ti and V ions in the blood and especially in tissues around the titanium growth guidance sliding device LSZ-4D accompanied by clinical manifestations (seroma and sinuses) indicates the importance of improving wear resistance of such instrumentation with the coatings and the necessity to exchange sliding instrumentation once the child is fully grown. © 2016 Elsevier Inc. All rights reserved.

**Keywords:** Metal ion content; Metallosis; Scoliosis; Sliding instrumentation; titanium; wear

## Introduction

Fusionless instrumentation enabling growth of the spine is used for early-onset scoliosis treatment or for the treatment of adolescent scoliosis in case of high growth potential to avoid early fusion in pediatric patients. Mechanically or magnetically extendable rods are widely used for this purpose [1,2]. These extendable growing rods require intermittent extension (at least twice a year). Long-term complication of proximal junction kyphosis is another drawback of these devices [3]. In growth guidance sliding instrumentation such as Shilla (Medtronic, Minneapolis, MN USA) or LSZ-4D (CONMET, Moscow, Russia), unlocked fixtures are used, allowing the rods to slide during growth of the child's spine, thus avoiding periodical extensions [4,5].

Potentially, as these rods slide in the guiding fixtures, excessive metal debris (metallosis) could be generated. Metallosis associated with CoCr debris generated at the articulation of metal-on-metal total hip prosthesis is associated with pseudotumors and sensitivity to metal debris, and is the main reason for the revision of these implants [6]. Excessive amounts of more biologically compatible Ti wear debris produced by spinal implants have been reported to cause inflammation and osteolysis in animal experiments [7–9]. A case report identifying wear debris-induced osteolysis around a pedicle screw after posterior spine fusion in a pediatric patient has recently been reported [10].

However, the probability of clinical complications associated with metallosis after implantation of fusionless growth guidance sliding spinal instrumentation is poorly understood because these devices have just been recently released. The question of changing other fusionless instrumentation into a more traditional fusion device after a child's growth has stopped has also not yet been addressed because there are no long-term follow-up studies with such spinal instrumentation.

Extensive analysis of wear damage of total hip and knee replacements revealed that excessive debris release is normally accompanied by the increasing metal ion levels in the patient's whole blood and serum [11,12]. Increases of Ti ion levels in the blood of patients with implanted titanium spinal instrumentation were reported by Cundy et al. [13], Kasai et al. [14], and Richardson et al. [15], even in arthrodesis procedures. Elevated Ti ion concentration of up to 50 times the normal levels was observed by Wang et al. in tissues surrounding spinal implants [16].

However, the content of metal ions in the blood and tissues of pediatric patients treated using fusionless, especially growth guidance sliding, instrumentation, has not yet been investigated. The aim of our study was to measure the content of metal ions in the blood and tissues that surround the implanted growth guidance sliding LSZ-4D devices made of titanium alloy (Ti6Al4V), and to identify the incidence of metallosis-associated clinical complications in some patients with these devices. It was hypothesized that the level of metal ions in the blood and tissues of patients after implantation of sliding growth guidance instrumentation would be higher than the level of metal ions previously reported for traditional fusion spinal devices.

## Materials and methods

### *Study design and participants*

This is a one-center, case-control retrospective study. Twenty-five patients (3 males and 22 females with high growth potential, and with an average age of  $11.4 \pm 1.2$  years old at primary surgery) who had sliding growth guidance instrumentation LSZ-4D (CONMET) implanted for  $6 \pm 2$  years were recruited into the study group for measurements of metal ion content in their whole blood and tissues. Recruitment was carried out at the Center for Scoliosis Correction Medical Department of the Peoples' Friendship University of Russia (Moscow, Russian Federation) from May to October 2013. These patients were undergoing the routine surgery of exchanging the sliding LSZ-4D devices with traditional fusion instrumentation when they became skeletally mature (second surgery).

The LSZ-4D sliding instrumentation is made from titanium alloy Ti6Al4V (Ti-6wt. %Al-4wt. %V) and consisted of two rectangular section rods (6×4mm) and  $40 \pm 8$  fixture elements ( $20 \pm 4$  hooks and  $20 \pm 4$  clips). Locked fixtures were used on one spinal level. Other fixtures were unlocked (sliding), enabling sliding and continued spinal growth (Fig. 1). The device was implanted on 13 (range: 10–16) spine levels for  $6 \pm 2$  years (Table). According to the Lenke classification [17], patients in the study group had the following types of scoliosis: 1—IA+; 1—IBN; 7—IIBN; 7—IIIBN; 7—IIICN; 1—IVCN; 1—VCN.

Approximately 80%–90% of correction was achieved for patients who have an initial Cobb angle of less than  $60^\circ$  (N=8),

## EVIDENCE & METHODS

### Context

The potential for the development of metallosis in children with significant growth potential treated with titanium alloy growing rods for scoliosis has been theorized to be high. The incidence of this condition and associated complications around its development have not been well explored.

### Contribution

The authors present their experience with 25 children treated using growth guidance sliding treatment devices. High levels of metal ions were encountered in the adjacent tissues in children treated with these growth guidance sliding devices. Five patients developed metallosis-associated complications.

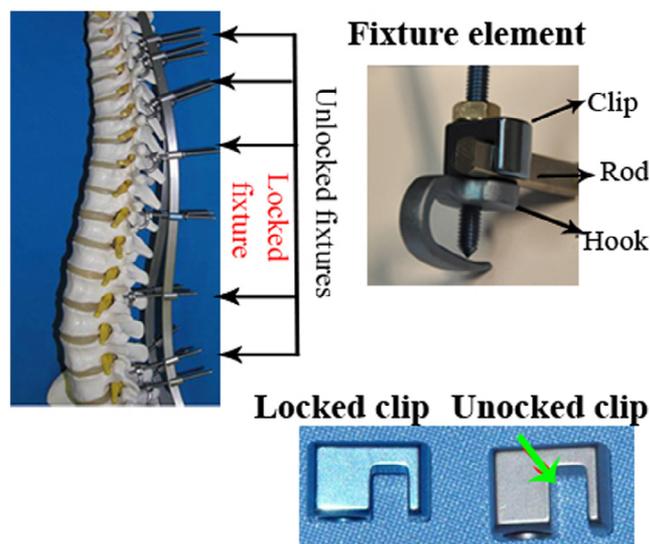
### Implications

This study provides useful information that may be used in patient counseling and expectation management with respect to the potential for the development of metallosis. The work also highlights areas of future research. Given the sample size and limitations associated with the study design, however, this study presents Level IV evidence.

—The Editors

whereas 70%–78% of correction was achieved for those with an initial Cobb angle of more than 60° (N=17).

To measure the Ti, Al, and V metal ion content, blood was collected on the day before such routine surgery, whereas tissues around the rod and screw junction were collected during



Unlocked clip has deeper groove for sliding of the rod

Fig. 1. Illustration of LSZ-4D sliding growth guidance device. Locked fixture is used at one spinal level. Unlocked fixtures are used at the distal and proximal end of the device, enabling sliding and continued spinal growth.

the surgery. Any incidence of metallosis-related complications in the study group was recorded.

Metal ion levels and tissue analyses were also carried out in the control group consisting of 13 patients (1 male and 12 females, 11±1.2 years old) with no implanted devices. These patients were recruited at the same center during the same period before they had their primary surgery for scoliosis.

### Measurement of metal ions in the whole blood and tissues

The content of Ti, Al, and V metal ions was measured in the whole blood and tissues of patients from the study and control groups.

To limit possible contamination, venipuncture was performed with cannula. Venous blood specimens were collected into the green-cap Vacuette (sodium heparin-containing) collecting tubes (Greiner Bio-One International AG, 4550 Kremsmünster, Austria) and diluted 1:30 with an acidified diluents ([vol/vol] of 1% 1-butanol, 0.1% Triton X-100, and 0.07% HNO<sub>3</sub> in distilled deionized water). The amounts of titanium, aluminum, and vanadium were measured using inductively coupled mass spectrometry method using NexION 300D ICP-MS spectrometer (PerkinElmer Inc, Shelton, CT, USA).

Soft tissues were taken at the time of surgery from the capsule surrounding the fixture-rod junction and 3 cm away from the capsule. Tissue specimens were digested with HNO<sub>3</sub> in the Berghof SW-4 DAP-40 microwave system (Berghof Products + Instruments GmbH, Eningen, Germany), diluted 1:150 with distilled deionized water and run into the inductively coupled mass spectrometry method system within 2–3 hours to prevent possible precipitation of titanium salts.

Histologic examination of tissues was carried out using light microscopy (AXIOSKOP 2 Pplus microscope, Carl Zeiss AD, Jena, Germany). For light microscopy, formalin-fixed and paraffin wax embedded sections of 4-µm thickness were taken and stained with hematoxylin and eosin. Titanium particles appear black in stained histologic sections, and their composition was confirmed using energy dispersive x-ray analysis.

### Statistical methods

The number of patients in the study and control groups (25 and 13, respectively) was calculated using the G\*Power 3.1.7 software (Dusseldorf University, Dusseldorf, Germany) based on the data from internal pilot study.

After metal ion content was measured in all patients, the Mann-Whitney *U* test was used to determine if there was statistically significant difference in the Ti, Al, and V content in the blood of patients with implanted LSZ-4D device and in those from the control group. A *p*-value of less than .05 was defined as statistically significant. This test was chosen after Kolmogorov-Smirnov test revealed that metal content in blood and tissues significantly deviated from a normal distribution. This statistical analysis was performed using the

Table  
Clinical information and metallosis-related complications observed in the study group of patients with implanted LSZ-4D sliding devices

Patient number	Gender	Age at implant	Number of operated levels	Lenke scoliosis type	Implantation time (years and months)	Metallosis-related complications
1	Female	13	14 (T2–L4)	IIBN	5 y and 10 mo	
2	Female	12	10 (T4–L2)	IIBN	3 y and 6 mo	
3	Male	10	10 (T2–T12)	IA+	3 y and 6 mo	
4	Female	11	13 (T2–L3)	IIBN	5 y	Fistula with inflammation (5 y after surgery)
5	Female	12	14 (T2–L4)	IIIBN	10 y and 1 mo	Seroma, paleness, elevated body temperature, weight loss (10 y after surgery)
6	Female	11	14 (T2–L4)	IIICN	5 y	Seroma (1 y after surgery)
7	Female	13	14 (T3–L5)	IIICN	5 y and 5 mo	Seroma, fistula without inflammation (2 y after surgery)
8	Female	12	14 (T2–L4)	IIBN	6 y	Seroma (6 mo after surgery)
9	Female	12	15 (T2–L5)	IIIBN	10 y	
10	Female	13	14 (T2–L4)	IIICN	6 y	
11	Female	10	14 (T2–L4)	IIIBN	3 y and 6 mo	
12	Male	13	15 (T2–L5)	IIICN	8 y and 3 mo	
13	Female	11	16 (T1–L5)	IVCN	6 y and 3 mo	
14	Male	13	15 (T2–L5)	IIIBN	5 y and 4 mo	
15	Female	10	14 (T2–L4)	IIIBN	7 y and 4 mo	
16	Female	13	14 (T3–L5)	IIICN	8 y and 2 mo	
17	Female	10	14 (T2–L4)	IIICN	4 y and 2 mo	
18	Female	12	14 (T2–L4)	IIIBN	5 y and 6 mo	
19	Female	11	10 (T4–L2)	IIBN	4 y and 2 mo	
20	Female	10	14 (T2–L4)	IIIBN	5 y and 6 mo	
21	Female	11	14 (T3–L5)	VCN	5 y and 6 mo	
22	Female	10	14 (T2–L4)	IIBN	4 y and 6 mo	
23	Female	12	14 (T2–L4)	IIBN	5 y and 1 mo	
24	Female	11	15 (T2–L5)	IIICN	4 y and 1 mo	
25	Female	10	10 (T2–T12)	IBN	5 y and 3 mo	

SPSS 22.0 software (IBM Corp, Armonk, NY, USA). The same test was carried out for two subgroups of the study group of patients (those who developed metallosis-related complications and those who did not). Because of the small number of patients in the subgroup with metallosis complications, power of this test was calculated.

## Results

### *Metallosis-associated complications*

Five of 25 patients in the study group who returned to the clinic to undergo surgery of exchanging the sliding growth guidance titanium LSZ-4D devices with traditional fusion instrumentation developed metallosis-associated complications in the lumbar part of the spine (Table).

Two of such patients required revision surgery because of these complications. One of these patients developed seroma accompanied with elevated body temperature and increased erythrocyte sedimentation rate in her blood, which were regarded as signs of inflammation 10 years after the surgery. The second patient developed a sinus with local inflammation 5 years after the surgery. Clinical symptoms were resolved once the device had been exchanged or shortened. In both of the revised cases, exhaustive microbiological analysis of the samples taken during revision surgery using both aerobic and anaerobic bacterial cultures failed to identify any organisms.

Another three patients developed seroma or sinus without inflammation 0.5 to 2 years after implantation of the LSZ-4D devices (Table). However, these seroma and sinus were successfully treated by compression dressing and antibiotic therapy, and the patients were recommended to avoid intensive physical exercises. Antibiotic therapy was used as a precaution to prevent revision surgery.

### *Content of metal ions in the whole blood*

The median values of titanium, aluminum, and vanadium in the whole blood of patients from the control group without implants were 30 ppb (range: 30–40) for titanium, 30 ppb (range: 20–40) for aluminum, and 0.08 ppb (range: 0.06–0.1) for vanadium. Patients with implanted LSZ-4D sliding devices had much higher ion levels with 85 ppb (range: 28–180) of titanium, 30 ppb (range: 18–150) of aluminum, and 0.3 ppb (range: 0.2–0.5) of vanadium. Statistical analysis using Mann-Whitney non-parametric test revealed statistically significant ( $p=0.0001$ ) raised levels of titanium and vanadium (2.8 and 4 times, respectively) in the whole blood of patients with implanted LSZ-4D devices (Fig. 2). However, the content of aluminum in the whole blood of patients in the control and study groups was not statistically significant ( $p=0.16$ ; power: 0.95) because of the variability associated with Al ion content in the study group (Fig. 2).

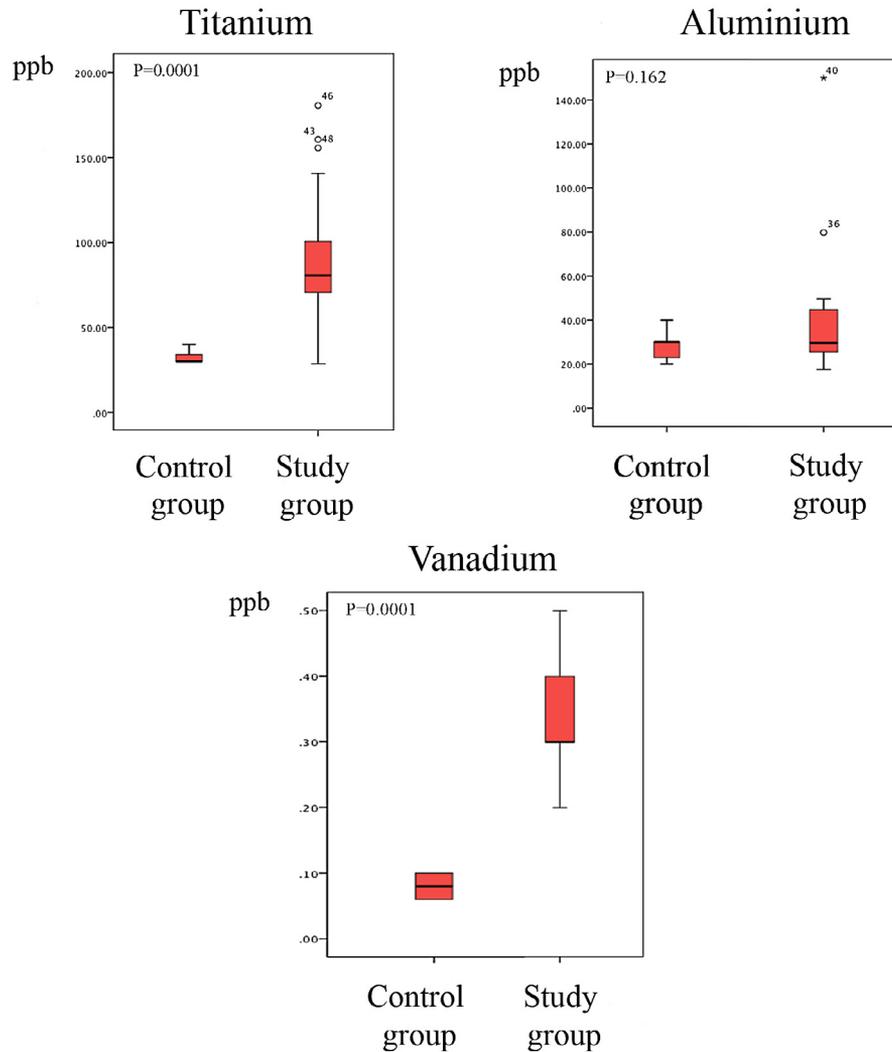


Fig. 2. Content of titanium, aluminum, and vanadium measured using the inductively coupled mass spectrometry (ICP-MS) method in the whole blood of patients from the control group (without implants) and from the study group (with implanted sliding LSZ-4D device for  $6 \pm 2$  years). Box lengths represent the interquartile range (first to third quartiles). The line in the center of the boxes shows the median value. Data indicated by “o” are outliers (being more than 1.5–3.0 times the interquartile range over the third quartile), and data flagged by “\*” are extreme values (more than three times the interquartile range over the third quartile).

The content of titanium, aluminum, and vanadium in the blood of patients with implanted LSZ-4D devices who had seroma and sinuses ( $N=5$ ) was also compared with that observed in the blood of patients who did not have these complications ( $N=20$ ). Statistical analysis revealed no statistically significant difference of Al and V ion content in these groups ( $p=.07$  and  $p=.05$  for aluminum and vanadium, respectively). Even slightly lower content of titanium was revealed in the blood of patients who developed these metallosis-associated complications ( $p=.035$ ). However, because of the small number of patients in the subgroup of patients with complications ( $N=5$ ), the power of the test was less than 0.80 (0.60 for Ti and V ions; 0.10 for Al), which might require further studies.

#### Content of metal ions in tissues surrounding implants

Black discoloration of soft tissues adjacent to growth guidance sliding LSZ-4D devices was observed in all patients, indicating significant amounts of wear debris (Fig. 3). The median concentration of titanium, aluminum, and vanadium in the soft tissues taken at the time of surgery in patients of control group operated for scoliosis for the first time and having no metal implants was  $0.7 \mu\text{g/g}$  (range: 0.15–0.95) for titanium,  $0.7 \mu\text{g/g}$  (range: 0.1–0.9) for aluminum, and  $0.06 \mu\text{g/g}$  (range: 0.01–0.1) for vanadium.

The median concentration of these elements in the tissues of patients with implanted growth guidance sliding devices LSZ-4D taken from the capsule around fixture-rod junction increased dramatically up to  $1,300 \mu\text{g/g}$  (range: 103–5,750)



Fig. 3. The intraoperative photograph shows the black discoloration of tissues in the lumbar part of the spine after disassembling the sliding LSZ-4D instrumentation at routine surgery to exchange this device with traditional fusion instrumentation when the child became skeletally mature (patient did not have any complications).

for titanium, 18  $\mu\text{g/g}$  (range: 2–106) for aluminum, and 11  $\mu\text{g/g}$  (range: 2–109) for vanadium, indicating statistically significant increase of all elements (Fig. 4).

The concentration of metal ions was measured in the soft tissues collected 3 cm away from the capsule, indicating that elevated ions were not only associated with capsular tissue adjacent to the implant but were also found at a deeper level. The median values were 6.5  $\mu\text{g/g}$  (range: 1.3–34) for titanium, 0.9  $\mu\text{g/g}$  (range: 0.4–6) for aluminum, and 0.1  $\mu\text{g/g}$  (range: 0.02–0.8) for vanadium, which are significantly higher compared with the control group, but significantly lower compared with the tissues collected from the capsule.

The content of metal ions in the soft tissues adjacent to fixture-rod junction was also compared between the subgroup of patients with implanted LSZ-4D device who developed metallosis-associated complications (N=5) and those who did not (N=20). No statistically significant difference was found for any compared elements ( $p=1.0$ ,  $p=0.77$ , and  $p=0.86$  for titanium, aluminum, and vanadium ions, respectively). Because of the high scattering of the metal ion content, the power of the test for all ions was much lower than 80% (0.10 for Ti, 0.3 for V, and 0.2 for Al).

#### *Histology analysis of tissues and metal debris particles*

Histology analysis of the tissues isolated from patients with implanted sliding LSZ-4D devices all showed a similar appearance. There were regions that contained macrophages with

large numbers of titanium particles. Individual particles could not be seen with light microscopy as they were of a small size. These macrophages often occurred in well-vascularized tissue, and there was an infiltration of plasma cells within the tissue. In other regions, there was necrosis where the cell number was reduced, and acellular regions of collagenous tissue were observed (Fig. 5).

#### **Discussion**

We are reporting the incidence of metallosis-associated complications that involved the formation of seroma and sinuses after implantation of titanium sliding growth guidance devices LSZ-4D in 5 of 25 patients. All cases of seroma and sinuses were observed in the lumbar part of the spine, which may be explained by the higher mobility of the lumbar spine region compared with the thoracic region.

The observed frequency of metallosis-associated complications (20%) is relatively high, regardless of the fact that only two of these five patients required revision surgery. However, the complication rates for other spinal instrumentation for scoliosis treatment in immature patients, such as the growing rods or Shilla devices, are also high [18,19] because the fusionless approach combined with periodic lengthening (growing rods) or sliding mechanisms (Shilla or LSZ-4D) necessary for retaining spinal growth of pediatric patients makes the treatment more complex compared with that used for adult patients.

Recent extensive analysis of metallosis-associated complications for metal-on-metal total hip replacements made of CoCr alloys revealed positive correlation between the content of cobalt ions in patients' blood and pseudotumor formation and implant loosening [11].

Back in the 1990s, it was also revealed that patients with failed titanium-on-polyethylene total knee and hip implants had several times higher titanium concentrations in their blood compared with subjects with normally functioning prostheses [12,20]. Because increased levels of metal ions in patients' blood were reported in the literature even after fusion spine surgeries, we hypothesized that the implantation of fusionless, and especially sliding instrumentation, would result in higher level of metal ions in the blood.

The results of our study revealed that 90% of subjects in the study group with implanted LSZ-4D sliding devices had increased Ti and V ion levels in the blood. The amount of Ti and V ions in the whole blood of these patients was increased 2.8- and 4-fold, respectively, compared with the whole blood of patients in the control group. No statistically significant difference was observed for Al content because of the scattering of its content. The content of V ions in the blood is higher than that of Ti and does not reflect the ratio of these elements in Ti alloy composition, which contains 6wt. % of Al and 4wt. % of V, which is possibly due to the excretion of titanium from the body and the retention of vanadium.

However, the increase of Ti content in the blood of patients after implantation of fusionless sliding LSZ-4D devices

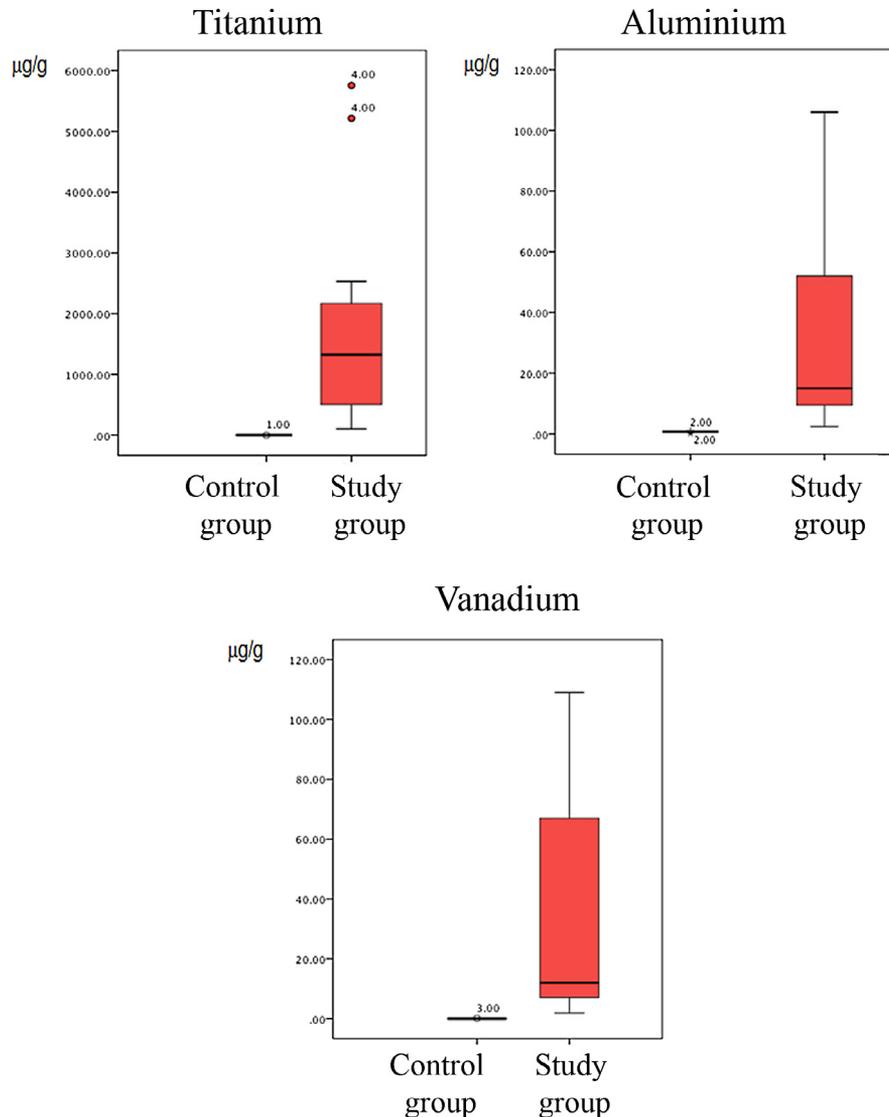


Fig. 4. Content of titanium, aluminum, and vanadium measured using the inductively coupled mass spectrometry (ICP-MS) method in the soft tissues directly adjacent to fixture-rod junction in the lumbar part of the spine of patients from the study group (with implanted sliding LSZ-4D device for 6±2 years) and from the control group (without implants).

in our study is similar to the values demonstrated by others who investigated patients with fusion devices.

Cundy et al. revealed 2.4-fold elevated level of titanium in pediatric patients after fusion surgery (9 spine levels) [13]. Kasai et al. and Richardson et al. reported 4-fold and 3.6-fold increases in adult patients' blood with instrumentation implanted on two or three levels of their lumbar spine [14,15]. Data presented by Ipach et al. also demonstrate two- to three-fold increases of Ti content in some adult patients with five fused segments [21]. Statistically significant correlation among the number of fused segments, length of rods, quantity of screws, and content of titanium in the blood was not found by Richardson et al. and Ipach et al. in their studies. However, the power of such comparisons in their studies might not be high because of the small number of patients in the tested subgroups [15,21].

Nevertheless, the number of operated spine segments might possibly be related to the number of patients who have increased Ti content. Ninety to ninety five percent of patients in our study (10–16 spine levels) and in that carried out by Cundy et al. (9–10 spine levels) demonstrated increased Ti content [13]. In contrast, only 35% and 65% of subjects with up to three spine segments fused had increased metal levels [14,15]. However, further studies with the same instrumentation would be necessary to support this hypothesis.

Similar increase of Ti in patients' blood was observed in previous studies, and the absence of statistically significant difference in these metal content in the subgroup of patients who developed seroma and sinuses and those who did not (power: 0.60 for Ti and V ions) might imply that the content of metal ions in the blood of patients with spinal instrumentation might not be used in predicting clinical

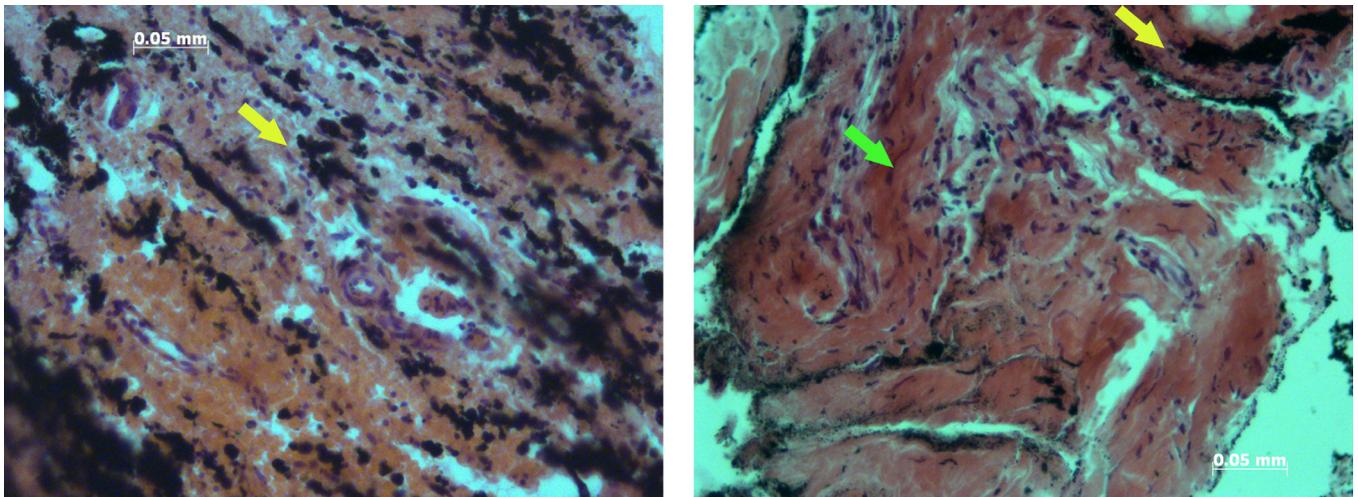


Fig. 5. Histology analysis of tissues surrounding LSZ-4D sliding device from a patient without complications (Left) and from a patient who developed seroma accompanied with elevated body temperature and increased erythrocyte sedimentation rate in the blood (Right) showing densely stained tissue and macrophages (yellow arrows) and areas of necrosis (green arrows).

complications such as seroma or sinus formation and the amount of wear debris generated by the spinal devices.

The content of metal ions in the soft tissues adjacent to spinal implants is not extensively covered in the literature. Wang et al. reported 30.36  $\mu\text{g/g}$  of titanium in the tissues of patients who developed pseudarthrosis after previous lumbar decompression and fusion with titanium pedicle screw instrumentation surrounding titanium spinal instrumentation, whereas 0.6  $\mu\text{g/g}$  was reported for patients who had solid fusion [16]. In our study, the content of metal ions, especially Ti, in the tissues surrounding the fixture-rod junction of sliding LSZ-4D device is dramatically higher, with 1,300  $\mu\text{g/g}$  compared with 0.7  $\mu\text{g/g}$  observed in tissues collected from the control group of subjects. Similar massive deposition of titanium debris (up to 3,700  $\mu\text{g/g}$ , average amount was 1047  $\mu\text{g/g}$ ) was reported by Agins et al. within the tissues that surrounded failed total knee implants [22].

Our previous work has revealed that more than 50% of wear particles retrieved from tissues that surrounded LSZ-4D devices are less than 0.400  $\mu\text{m}$  in size [23]. This is similar in size to that described for cobalt chromium and titanium wear particles retrieved from total hip replacements [24]. Histology observations of the tissues in the present study revealed high content of metal debris, macrophages, and even necrosis areas, which are often observed as an adverse inflammatory reaction of tissues to excessive metal debris after total hip replacements [25]. Based on these findings, it might be assumed that high concentrations of Ti and V ions in tissues surrounding sliding spinal implants LSZ-4D might possibly be the reason for such clinical manifestations as seroma and sinuses, some of which require surgical revision.

Based on the results of the present study, which revealed increased content of Ti and V ions in the blood of 90% of patients in the study group, high levels of metal content in the tissues around the sliding device, and cases of clinical com-

plications like seroma and sinuses, it might be concluded that additional efforts for improving the wear performance of growth guidance sliding instrumentation are necessary to fully exploit the benefits of such instrumentation. Because the biocompatibility of Ti is much higher compared with Co and Cr, which are present in CoCr and stainless steels, it might be hypothesized that the optimization of titanium instrumentation design and improvements in its wear resistance by application of biocompatible wear-resistant coatings would certainly be beneficial.

#### Limitations of the study

The limitation of the present study is that our results are from a specific sliding device that has been used clinically. Although this device uses similar materials to those used in other spinal instrumentation, the volume of wear debris released will be dependent upon the design and the way the rods are fixed. Nevertheless, our findings indicate the importance of using wear resistance materials for sliding and extending instrumentation, which is used for the treatment of scoliosis in immature patients. It also indicates that replacement of the sliding and possibly extending devices in the spine after the completion of growth would be important as continual small cyclic movements may generate significant wear particle that has the potential to be problematic.

#### Conclusions

Five of 25 patients with implanted growth guidance sliding LSZ-4D devices made of titanium alloy Ti6Al4V developed metallosis-associated complications. Two patients had sinuses and three had seroma in the lumbar part of the spine. The content of Ti and V ions in the whole blood of 90% of patients with implanted LSZ-4D devices was in-

creased compared with the control group (2.8 and 4 times, respectively) but did not exceed the values reported previously in the literature for fusion spinal instrumentation. The median content of Ti ions in the soft tissues adjacent to implanted sliding device was measured to be more than 1,500-fold higher compared with the control group, which is a much higher level than previously reported for spinal instrumentation. No statistically significant difference in metal ion content in the blood (power: 0.60 for Ti and V ions) was revealed in patients with and without metallosis-associated complications. Our findings imply that either the use of wear-resistant coatings on titanium alloy sliding devices or the use of a different material for such instrumentation would be beneficial.

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