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SEVERE METALLOSIS AFTER POLYETHYLENE LINER DISLOCATION IN CERAMIC-ON-Ti6Al4V TOTAL HIP ARTHROPLASTY. A CASE STUDY

HUDA METALOZA PO DISLOKACIJI POLIETILENSKEGA VLOŽKA PRI KERAMIČNO-TITANOVI Ti6Al4V TOTALNI KOLČNI ENDOPROTEZI. ŠTUDIJ PRIMERA

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Dislocation of the Polyethylene liner (HXPE) from the Ti6Al4V metal alloy cup was accompanied by severe metallosis and represents a rare complication after total hip arthroplasty (THA) in the first months after surgery. Understanding the risk factors for liner dislocation has great clinical relevance for every hip surgeon when considering different surgical options for effective planning and treatment. The liner placement, liner locking mechanism, impingement, surgical technique all play a crucial roll in keeping the liner within the acetabular cup. We present a case study of a 61-year-old female patient who was admitted to our clinic for revision surgery after THA due to pain, limited range of motion, audible crepitus, and radiographic signs of acetabular polyethylene inlay wear. The initial THA was performed 18 months prior. There were no signs of aseptic loosening or infection. Based on these findings and the clinical presentation, revision surgery was deemed necessary. Scientific databases were accessed to identify research papers dealing with the prevention and treatment of liner dislocation after THA. We performed a search using the keywords 'revision hip arthroplasty' and 'dislocation', 'instability', 'outcome', 'failure', 'treatment'. The retrieved implant parts, ceramic acetabular head, HXPE liner and Ti6Al4V alloy acetabular cup were the object of a detailed tribological investigation. Digital stereo light microscopy was used for large parts and surfaces, Field Emission Scanning Electron Microscopy with integrated EDS technique and low vacuum Scanning Electron Microscopy were used to investigate the detailed surface chemistry of the metal alloy, ceramics and the thin film of titanium alloy on the surface of the ceramic head. It was found that the thin metallic layer is formed due to tribological transfer of metal from the taper stem and the inner of the acetabular cup. Risk factors were analysed to establish the most relevant and evidence-based treatments available in the current literature. This case highlights the early-onset of metallosis following polyethylene liner dislocation in total hip arthroplasty, leading to a ceramic-on-metal contact and acetabular cup wear. The likely cause was excessive torsional force from a fall, overcoming the liner's locking mechanism. The risk of dislocation after THA can be reduced using some precautions inferred from the literature. The use of a larger femoral and acetabular component, elevated rim liner and dual mobility implants can significantly reduce the risk of dislocation after THA. However, care must be taken regarding patient-related the risk factors since these cannot be addressed and modified. Hence, a complete evaluation of risk factors should be performed for each patient and procedure before starting THA.

Keywords: revision, dislocation, metallosis, hip arthroplasty

Izpah polietilenskega vložka (HXPE) iz acetabularne komponente iz kovinske zlitine Ti6Al4V je spremljala huda metaloza, ki predstavlja redek zgodnji zaplet po popolni artroplastiki kolka (THA) v prvih mesecih po posegu. Razumevanje dejavnikov tveganja za dislokacijo ima velik klinični pomen za vsakega ortopedskega kirurga, da razmisli o vseh kirurških možnostih za učinkovito načrtovanje posega. Položaj polietilenskega vložka, uzstreznost zaklepnega mehanizma vložka, femoralno vkleščenje in kirurška tehnika so ključni pri zagotavljanju stabilnosti polietilenske obloge. Predstavljamo študijo primera 61-letne bolnice, ki je bila sprejeta v klinično obravnavo za revizijski kirurški poseg po THA zaradi bolečine, omejenega obsega gibanja, slišnega škrtanja in radiografskih znakov izpaha acetabularnega polietilenskega vložka. Začetna THA je bila opravljena pred 18 meseci. Ni bilo znakov aseptičnega omajanja ali okužbe. Na podlagi teh ugotovitev in klinične slike je bila indicirana revizijska operacija. Uporabili smo znanstvene podatkovne baze za identifikacijo strokovnih člankov, ki se ukvarjajo s preprečevanjem in zdravljenjem izpaha acetabularnih vložkov po THA. Iskanje smo izvedli z uporabo ključnih besed "revizijska artroplastika kolka" in "dislokacija", "nestabilnost", "izid", "neuspeh", "zdravljenje". Predmet preiskave so bili pridobljeni odstranjeni deli proteze deli, keramična acetabularna glava, HXPE vložek in acetabularna komponenta iz zlitine Ti6Al4V. Digitalni stereo svetlobni mikroskop je bil uporabljen za vizualizacijo velikih vzorcev, vrstični elektronski mikroskop na poljsko jakost z integrirano tehniko EDS in nizkovakuumski vrstični elektronski mikroskop pa sta bila uporabljena za podrobne razisave površinske kemije kovinske zlitine, keramike, in tanke plasti titanove zlitine na površini keramike. Ugotovljeno je bilo, da tanka kovinska plast nastane zaradi tribološkega prenosa kovine na stiku med konusom stebla in notranjosti acetabularne skodelice. Analizirali smo dejavnike tveganja, da bi ugotovili najpomembnejše in na dokazih temelječe zdravljenje, ki je na voljo v trenutni literaturi. Ta primer poudarja metalozo po izpahu polietilenske obloge pri popolni artroplastiki kolka, kar vodi do stika keramike s kovino in obrabo acetabularne komponente. Verjeten vzrok je bila prekomerna torzijska sila zaradi padca pacientke, ki je presegala zaklepne mehanizme vložka. Tveganje za izpah po THA je mogoče zmanjšati z nekaterimi previdnostnimi ukrepi, ki izhajajo iz literature. Ciljni kirurški ukrepi, ki lahko bistveno zmanjšajo nevarnost izpaha in

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acetabularne komponente so uporaba večje stegnenične glavice, povišan rob polietilenskega vložka ali acetabularna komponenta z dvojno gibljivostjo lahko bistveno zmanjšajo nevarnost izpaha in acetabularne komponente so ciljni kirurški ukrepi. Potrebno je razumeti, da določene dejavnike tveganja, povezane s pacienti, ni mogoče obravnavati in spremeniti. Zato je potrebno pred začetkom THA opraviti popolno oceno dejavnikov tveganja za vsakega bolnika posebej.

Ključne besede: revizija, dislokacija, metaloza, artroplastika kolka

1 INTRODUCTION

Total hip arthroplasty (THA), is widely regarded as one of the major surgical breakthroughs of the 20th century. It remains the most successful method for treating end-stage hip arthritis in elderly and younger patients. With well-established surgical approaches and continual advances in implant technology, particularly in the development of materials, coatings and bearing surfaces, the success rates and longevity of THA implants have significantly improved.[1–3]

In THA the damaged bone and cartilage are removed and replaced with prosthetic components, as shown in **Figures 1** and **2**.

The damaged femoral head is removed and replaced with a metal stem (titanium alloys: Ti6Al4V and Ti6Al7Nb, or rarely CoCrMo alloy) placed into the femur's hollow centre. The femoral stem may be either cemented (Polymethyl methacrylate PMMA) or non-cemented (press fit into the bone).

A metal or ceramic head is placed on the upper part of the stem. This head replaces the damaged femoral head that was removed.

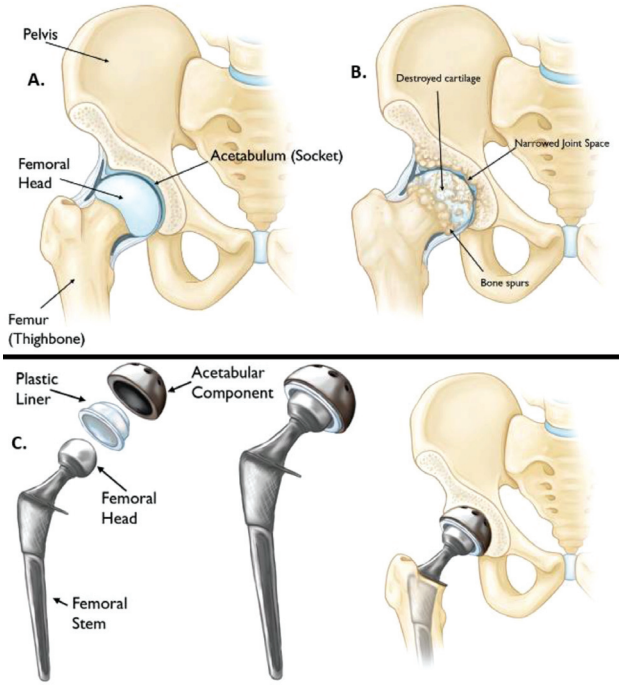

Figure 1: (A.) Normal hip anatomy, femur, femoral head, acetabulum and pelvis; (B) In hip osteoarthritis, the smooth articular cartilage wears away and becomes frayed and rough (C) The individual components of a total hip replacement with the components.[4]

The damaged cartilage surface of the socket (acetabulum) is removed and replaced with a metal socket.

A polymer (Ultra-High Molecular Weight PolyEthylene (UHMWPE), Highly Crossed PolyEthylene (HXPE), ceramic, or metal spacer (also called a liner) is inserted between the new head and the socket to allow for a smooth gliding surface.

THA is a very successful procedure. However, it does have a set of complications among which infection, aseptic loosening, and peri-prosthetic fractures are the most common reasons for revision surgery,[1–7]

Metallosis with an estimated rate of roughly 5 % can have severe detrimental consequences on a patient's health.[5,6] It is caused by metallic erosion and a consequential local increase in small metallic particles which cause local and even systemic effects.[5,6] More often it appears in metal-on-metal prosthetics, but it can occur in other prosthetics as well, usually following component failure.[6,7]

We present a case of early-onset metallosis after THA due to polyethylene liner dislocation leading to ceramic-on-metal contact and subsequent acetabular metal component wear. Combined with advanced tribological analysis we can share more insight into the cause and genesis of metallosis in modern THA prosthesis.

2 CASE REPORT

A 61-year-old female was admitted to the hospital for revision surgery after total hip arthroplasty (THA) due to pain, limited range of motion, audible crepitus, and radiographic signs of acetabular polyethylene inlay wear.

The initial THA surgery was performed 18 months prior due to hip dysplasia-induced osteoarthritis. The procedure and the rehabilitation protocol were carried out in accordance with the in-clinic protocol and were uneventful. Fourteen months after the initial surgery, the patient fell and suffered a contusion on the operated side. The initial radiographic evaluation showed no evidence of fracture or displacement of prosthesis components. However, in the weeks following the incident, the patient began reporting progressively worsening pain localized to the greater trochanteric region. Audible crepitus emerged shortly thereafter and became increasingly pronounced over time. Seventeen months after the initial surgery, the patient presented for a follow-up evaluation, citing persistent and debilitating pain. Repeat radiographs demonstrated cranial migration of the femoral head within the acetabulum, consistent with advanced polyethylene inlay wear (**Figure 2**). There were no ra-

Figure 2: Cranial migration of the femoral head within the acetabulum in two projections (Dept. for Orthopeadic Surgery, UMC Ljubljana)

diographic signs of aseptic loosening. Based on these findings and the clinical presentation, revision surgery was deemed necessary.

Intraoperatively, the superficial layers of tissue appeared unremarkable, with no evidence of inflammation. Upon incision of the fascia, a dark, viscous effusion was observed emanating from the hip-joint cavity (**Figure 3A**). The joint capsule and adjacent soft tissues exhibited pronounced discoloration, characterized by a dark-greyish-black pigmentation. Examination revealed a dislocated and damaged polyethylene inlay within the metal acetabular shell, which demonstrated significant wall thinning and ceramic acetabular head with thin Ti6Al4V film is shown in **Figure 3D**, **Figure 3E** shows new acetabular ceramic head.

The surrounding soft tissues showed no evidence of necrosis or structural compromise. A comprehensive irrigation and debridement of the joint cavity were performed. The acetabular component was explanted and replaced with a new acetabular component (size 50), secured using three trans acetabular screws. The femoral head was exchanged for a new ceramic head (size 32), while the femoral stem was retained as it exhibited no signs of damage, malalignment, or loosening. Removed prosthetic components and tissue specimens were obtained for microbiological and histological analysis. A histopathological examination confirmed a diagnosis of severe metallosis, while microbiological cultures returned negative for bacterial and fungal growth. The removed prosthetic components, after microbiological analysis, were cleaned, sterilised and sent for further tribological analysis. Postoperative radiographs showed a satisfactory position of the implants.

3 MATERIALS AND METHODS

3.1 Implant

The initial implant was of Adler Ortho, Milano, Italy, type Fixa Larus acetabular cup size 48, Cross-linked PE insert flat with 32 mm radius, APTA-fix cementless stem cone standard size 2.

3.2 Sample preparation

The retrieved stem was cut using a Struers's saw for the preparation of metallographic samples and for other investigations. For surface chemistry measurements and microstructure analyses the samples were prepared by grinding using the SiC 220 grinding paper (1 min), followed by polishing with MD Largo 9 m blue lubricant (5 min), and oxide-polished with MDCHEM OP-S (STRUERS GmbH, Zweigniederlassung, Austria) and H_2O_2 (10 min). The samples were additionally etched with Kroll's reagent in preparation for bulk microstructure analyses.

3.3 Microbiological analysis

All the implants removed during surgery were processed using sonication followed by microbiological analyses at the Institute for Microbiology, UMC Ljubljana. Both PCR and standard cultures for aerobic and anaerobic bacteria were used. Following the microbiological analysis, implants were cleaned and sterilised.

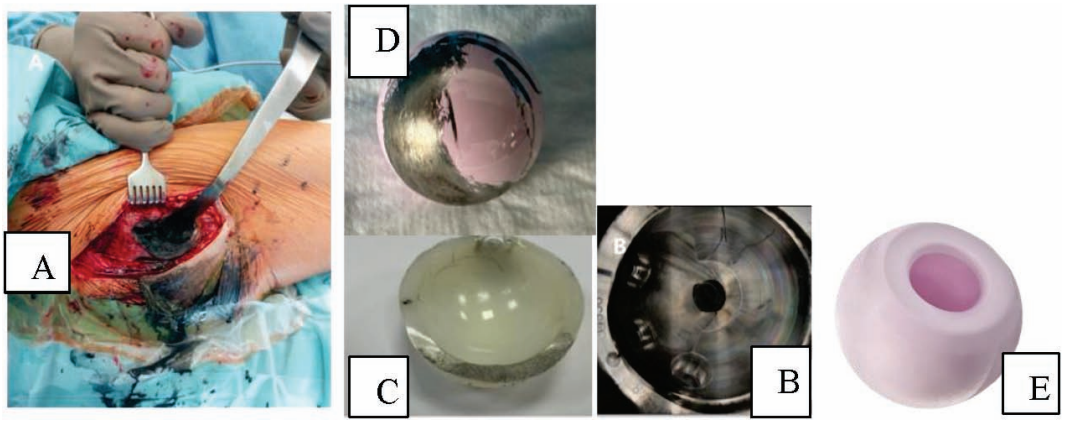

Figure 3: (A) Dark viscus metal effusion was found during the surgery of patient at UMC Ljubljana, (B) SLM image of the inside of acetabular component and (C) acetabular HX PE inlayer, both showing signs of wear and wall thinning, (D) ceramic acetabular head with the thin Ti6Al4V film due to tribological material transfer from Ti6Al4V stem and acetabular shell friction to the surface of ceramic (Aluminum oxide matrix consisting of approximately 80 % alumina, 17 % zirconia and 3 % strontium oxide), (E) new acetabular head, biolox delta ceramics.

3.4 SLM Stereo light microscopy

A stereo light microscope, vhx-x1F digital, Keyence, Japan, was used for the visualization of the wear pattern in the Ti6Al4V acetabulum, PE inlay and the ceramic femoral head.

3.5 Scanning Electron Microscopy, EDS energy dispersive x-ray spectroscopy

All the contact surfaces were analysed using the Scanning Electron Microscope, Zeiss CrossBeam 550, Germany and EDS detector Octane Elite using Apex (Edax, USA).

The low vacuum Scanning Electron Microscope Apreo 2S of Thermo Fisher, USA with the integrated EDS detector Ultim Max, AZtec of Oxford Instruments, UK, was used for the analysis of the whole inside acetabular.

The SEM SE Images were obtained with an accelerating voltage of 15 kV, at a working distance of 10 mm and current of 500 pA. Secondary electron (SE) and backscattered electron (BE) images were acquired. The samples elemental composition was analysed using EDAX APEX Software for EDS/EDX using the EDAX Octane Elite EDS/EDX System. The EDS spectra were obtained using a 15-kV, 1-nA electron beam with an acquisition time of 60 seconds per spectrum. The elemental composition and distribution within the sample were analyzed using INCA Energy software.

4 RESULTS AND DISCUSSION

The microbiology report of tissue samples taken, and the implanted material came up negative for pathogens using the PCR and culture growths. This finding along with X-ray imaging and the intraoperative report of a firmly ingrown acetabular component without signs of loosening, further confirmed our suspicion that the reason for the implant failure does not stem from septic implant loosening.

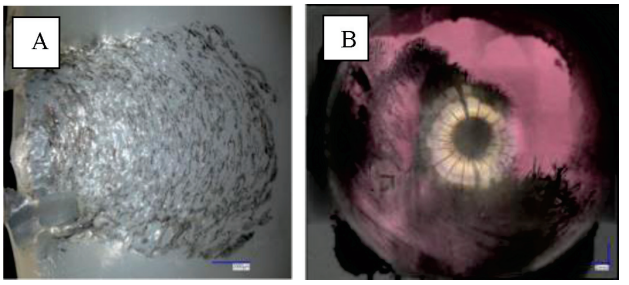

Figure 4: (A) SLM image of the HX PE inlayer wear, (B) SLM image of the Biolox Delta Ceramic femoral head with transferred thin Ti film, dark on the surface of delta ceramics head of pink colour, the golden yellow ring is due to the non-conductivity and charging of the sample, it was not possible to apply a thin layer of gold or palladium to prevent this phenomenon because the sample was too large to introduce it in the sputter device.

The SLM images show the surface wear on both the inlay (**Figure 4**), the acetabular component. **Figure 4A** shows dark spots on the ceramic head (**Figure 4B**). Although the hip resurfacing and THA surgery influence gait kinematics,[12] the wear on the acetabular component lays cranially on the acetabular component, which coincides with the position of peak contact pressure of the healthy hip joint during gait and standing as reported by both Gaffney et. al.[13] and Xiong et. al.[14] The dark spots on the ceramic head are caused by a metal transfer phenomenon[15] with possible metal transfer marks caused by surgical instruments during the revision surgery.

Table 1: EDS elemental analysis from the ceramic head surface EDS Spot2

Element	O	Al	Ti	V	Cr	Mn	Fe	Ni	Zr
w/%	39.1	36.3	3.7	0.0	2.8	0.1	9.0	1.8	7.3

This finding was further investigated by high vacuum and low vacuum SEM and EDS analysis. We analysed 7 different locations on the surface of the femoral head, **Figure 6**. All the samples were positive for the transfer of Ti, and traces of Al, V, while delta ceramics is of Al_2O_3 and ZrO_2 ions in similar proportions, all of which are usual components of alloys used to make metal prosthetic components and other biomaterials.[8,10] Certain spots contain traces of Cr, Mn, Fe, Ni ions (**Table 1**), all of which can be found in alloys, such as 316L stainless steel, used to make orthopaedic screws and surgical instruments. This finding does imply that during the prosthetic removal or possibly insertion, some surface metal transfer occurred from the surgical instruments to the acetabular head.

Catastrophic failures of THA are rare, with reported rates of 0.29 % to 10.9 % and with a 10-year survival

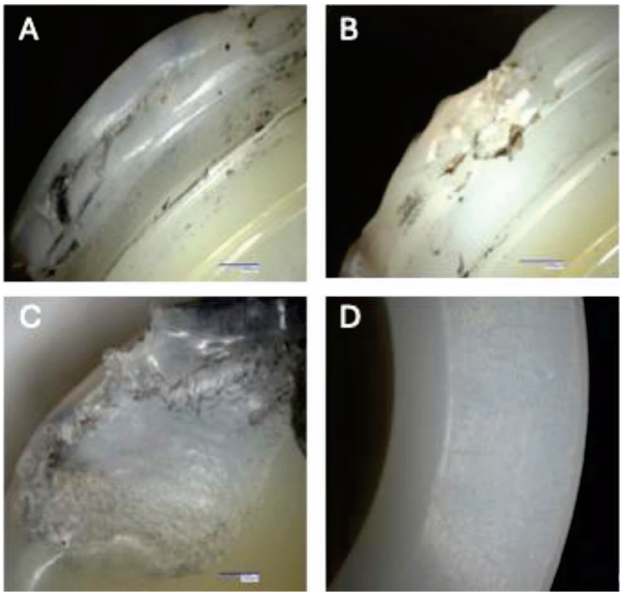

Figure 5: SLM images of retrieved damaged HX PE acetabular liner A, B, C and comparison with the new one D

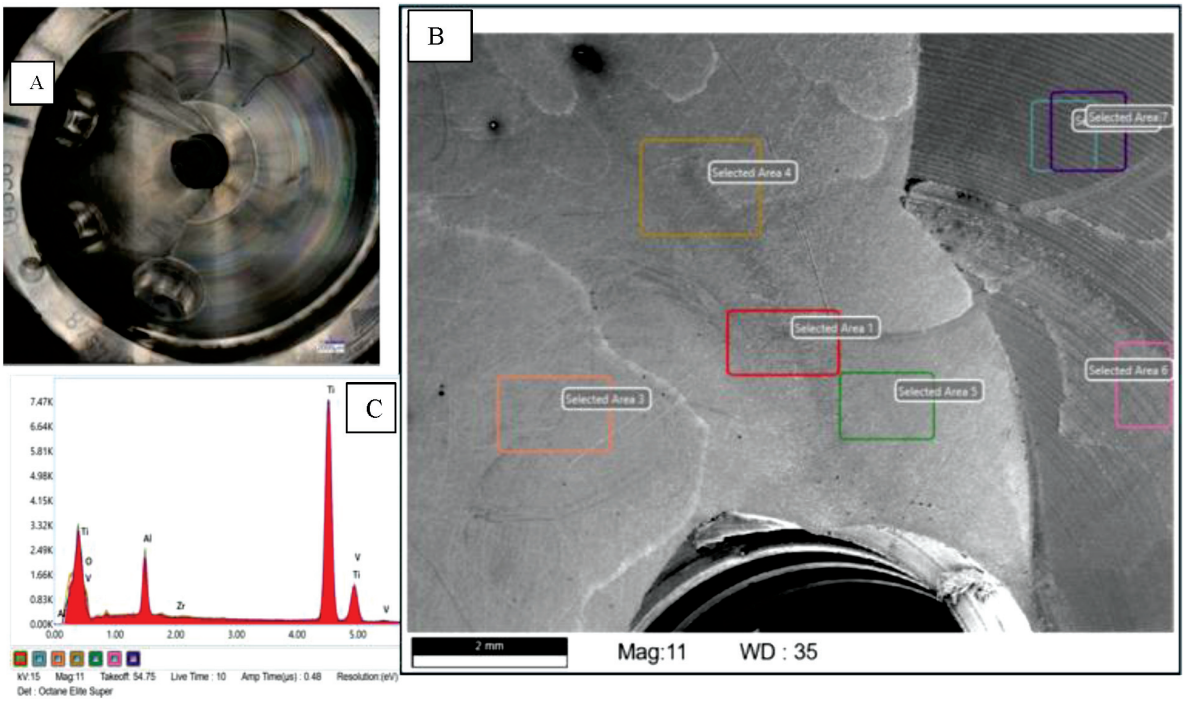

Figure 6: (A) SLM image of damaged acetabular cup, (B) SEM/BE image of detail from (A) with 7 selected area where EDS analysis was taken and (C) collected EDS spectra of all 7 selected area. It shows the EDS chemical analysis, of Ti, Al, O, and V elements, the traces of Zr are supposed to be from ceramic head. For the visualisation and EDS analysis Scanning Electron Microscope Apreo 2S of Thermo Fisher was used.

rate above 95 %[9,10] estimated to be in the range of 20-25 years.[2,7] The Adler Ortho acetabular cup Fixa Larus and Apta Fix femoral stem combination have been used 991 times in Slovenia between years 2019 and 2023 with a 4.4 % revision rate in this period which is twice the national average of 2.26 %, although the registry does not report liner luxation's individually.[17] The estimated rate of PE liner dislocation is 0.45 % and almost always warrants a surgical revision.[18] The failure occurred only 18 months after surgery and judging by the sudden onset of symptoms after the fall, we can assume that the dislocation of the PE occurred before the wear was sufficient to cause sufficient changes in the structural integrity of the PE. This is further investigated by the location of wear on the PE liner. As shown in **Figure 5**, it is located on the edge of the liner and does not correlate with the X-ray image of the placement of the acetabular cup after the initial surgery and the expected wear pattern. Certain risk factors such as malposition, impingement, high ranges of motion, liner wear and deterioration are known to increase liner dislocation susceptibility.[18] Although determining the key reason why the PE liner got displaced from the acetabular cup is difficult, it was most likely caused by a high increase in torsion force when the patient fell, which overcame the strength of the locking mechanism of the PE liner.

Removed prosthetic components and tissue specimens were obtained for microbiological and histological analysis. Histopathological examination confirmed a diagnosis of severe metallosis, as free metallic debris was shown to be present in the intraarticular fluid and tissue surface as well as in the tissue macrophages. The mechanism of debris formation was most likely caused by fretting which occurred between the harder ceramic surface of the head and the softer Ti6Al4V acetabular cup, further exacerbated by the surface incongruencies between the two, as shown in **Figure 6**. Metallosis can cause adverse tissue reactions and can cause systemic reactions caused by ion toxicity,[5–7,19] although our patient did not show any signs of such. We also did not notice any local bone lysis or prosthetic component loosening which can occur due to metallosis.[5,6,18] Microbiological cultures returned negative for bacterial and fungal growth, which further corroborates our explanation of mechanical failure of the inlay locking mechanism due to high peak torsion forces during the patient's fall.

5 CONCLUSIONS

This case highlights early-onset metallosis following polyethylene liner dislocation in total hip arthroplasty, leading to ceramic-on-metal contact and acetabular cup wear. The likely cause was excessive torsional force from a fall, overcoming the liner's locking mechanism.

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