ACTA ORTHOPAEDICA et TRAUMATOLOGICA TURCICA
www.aott.org.tr

Case Report

Peculiar reaction of oxidized zirconium from a total knee arthroplasty prosthesis: A case report

Jong Keun Seon[1], Khairul Anwar Ayob[2], Myung Giun Noh[3], Hong Yeol Yang[1]

[1]*Department of Orthopaedic Surgery, Chonnam National University Medical School and Hwasun Hospital, Hwasun-gun, Republic of Korea*
[2]*Department of Orthopaedic Surgery, National Orthopaedic Centre of Excellence for Research and Learning (NOCERAL), University of Malaya, Faculty of Medicine, Kuala Lumpur, Malaysia*
[3]*Department of Pathology, Chonnam National University Medical School and Hwasun Hospital, Hwasun-gun, Republic of Korea*

ARTICLE INFO

Article history:
Submitted May 20, 2023
Received in revised form August 24, 2023
Accepted December 5, 2023
Publication Date February 5, 2024

Keywords:
Oxidized zirconium
Metallosis
Polyethylene wear
Total knee arthroplasty

ORCID iDs of the authors:
J.K.S.: 0000-0002-6450-2339;
K.A.A.: 0000-0003-1651-1684;
M.G.N.: 0000-0002-0646-1997;
H.Y.Y.: 0000-0001-8730-9040.

ABSTRACT

Oxidized zirconium (Oxinium™) prostheses, made up of a metallic alloy of zirconium with a ceramic surface formed by oxidizing the outer layer, were developed as an alternative bearing surface to reduce polyethylene wear and decrease failure of total knee arthroplasty (TKA). We report a unique catastrophic failure of an Oxinium TKA with consequent accelerated wear and severe metallosis. Intraoperatively, we observed extensive wear grooving of the femoral component with exposure of the underlying silver layers and the complete wear of polyethylene on the medial side. Metallic debris had a peculiar arthrogram appearance, noted within the cut surface of the femur and tibia, indicative of the osteolysis that occurred, leading up to the failure of the implants. The histopathologic examination revealed a collection of macrophages with foreign-body reactions and black-pigmented metal-induced wear particles. Oxinium has clear benefits regarding superior wear properties; however, surgeons need to be aware that there is a risk of exposure to the underlying layers that may precede accelerated wear, deformation, and metallosis. Uncovering the deeper layers could result in the appearance of an arthrogram on plain radiographs. Early identification of polyethylene wear and prompt revision is crucial to avoid the rapid progression of subsequent metallosis and catastrophic implant failure, specifically when using oxidized zirconium components for TKA. To the best of our knowledge, this is the first report presenting a detailed histologic analysis to provide insight into the mechanisms of the failed Oxinium components.

Introduction

Total knee arthroplasty (TKA) is an established treatment option for end-stage knee osteoarthritis and has a survivorship exceeding 90% in the second decade.[1,2] The demand for arthroplasty is also increasing in the more active and relatively younger population, which calls for a better-performing prosthesis to cater to the higher levels of activity in younger patients. Thus, alternative bearing surfaces that show improved wear resistance are an area of extensive research because of the necessity for increased implant longevity.

Oxidized zirconium (Oxinium) comprises an outer ceramic layer produced from a wrought zirconium alloy (Zr-2.5Nb) that is oxidized by thermal diffusion in heated air to create a 5-μm-thick zirconia surface.[3] The oxide is a transformation of the original metal surface into zirconium-oxide ceramic.[4] Oxinium was developed to provide improvements to reduce wear when articulating against ultra-high-molecular-weig ht polyethylene (UHMWPE) and aseptic loosening in TKA due to its proposed benefits of resistance to roughening, frictional behavior, and biocompatibility over cobalt-chromium alloy.[3,4] It has also been used for patients with metal hypersensitivity and revision after metallosis.[5,6] The Genesis II Oxinium prosthesis (Smith & Nephew, Memphis [TN], USA) has shown satisfactory survival rates comparable to those of more traditional implants.[7,8]

However, there are some concerns about progressive wear and severe metallosis in oxidized zirconium implants.[8-10] Here, we present a unique case of catastrophic failure of oxidized zirconium TKA with resultant synovial deposits of oxidized zirconium and metallosis as a late complication. To our knowledge, this is the first reported case of clinical and histologic analyses of the mechanism of wear of failed Oxinium components.

Case presentation

A 76-year-old female with comorbidities, including hypertension and diabetes mellitus, had a TKA with a cemented Genesis II™ (Smith & Nephew) for her right knee osteoarthritis at another institution in March 2008. The femoral component was a cruciate-retaining Oxinium prosthesis, the tibial component was composed of titanium, and the insert was made from UHMWPE. She had an uneventful recovery and had no postoperative complications until 5 years after the primary TKA. At 10 years after the index surgery, she presented to the initial facility complaining of mild knee instability and received conservative treatment (Figure 1). Two years later, however, she presented to our institution with progressive pain and worsening instability. She also complained of difficulty in ambulating and knee swelling.

On physical examination, the incision was found to be well healed, and there was no joint effusion or

Corresponding author:
Hong Yeol Yang
stephano.h.yang@gmail.com

Cite this article as: *Keun Seon J, Anwar Ayob K, Giun Noh M, Yeol Yang H. Peculiar reaction of oxidized zirconium from a total knee arthroplasty prosthesis: A case report. Acta Orthop Traumatol Turc., 2024;58(1):68-72.*

DOI: 10.5152/j.aott.2024.23115

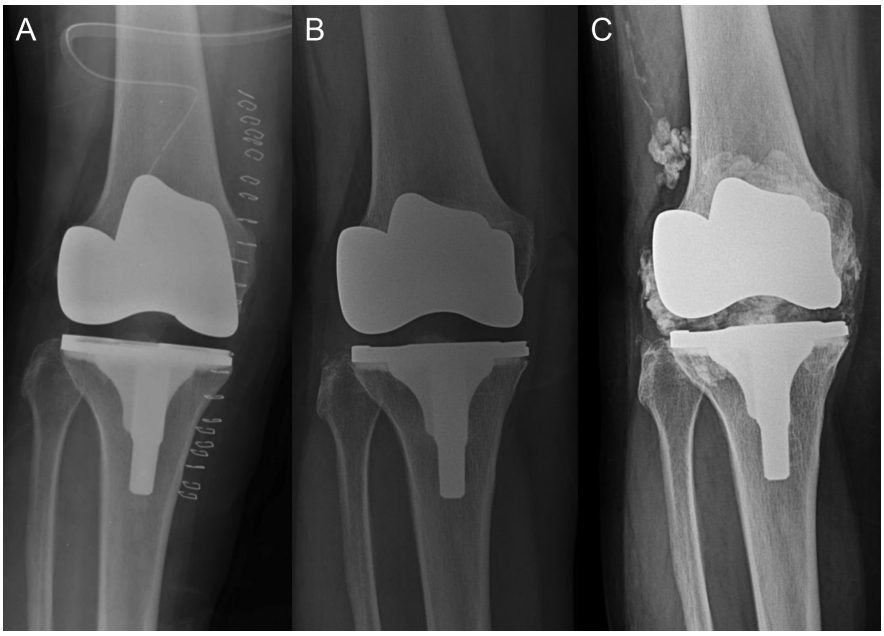

Figure 1. Serial postoperative anteroposterior radiographs (A) immediately, (B) at 5 years, and (C) 10 years following primary oxidized zirconium total knee arthroplasty.

erythema. Her range of motion was 0°-90° with palpable and audible crepitus. Mechanical hip-knee-ankle axis showed 2° of varus, and there was no significant laxity in the varus or valgus stress test. We used the Musculoskeletal Infection Society criteria to exclude periprosthetic joint infection after primary TKA.[11] Blood samples and joint aspirations were both assessed as within normal limits by our clinical medicine and microbiology department. Furthermore, the serum white blood cell count was in the normal range at 7.07K/μL (reference range: 4.8-10.8K/μL), the C-reactive protein count was 0.27 mg/dL (reference range: 0.0-0.3 mg/dL), and erythrocyte sedimentation rate was 23 mm/h (reference range: 0-20 mm/h), causing little concern for an infectious etiology.

Anteroposterior and lateral radiographs revealed a cemented TKA with obliteration of the polyethylene (PE) space on the medial side. There was also apparent grooving of the medial femoral condyle (Figure 2). The radiographs also revealed lobulated, bubble-shaped opacities following the outline of the joint capsule, extending from the suprapatellar pouch to the popliteal area of the knee. Bone scintigraphy and single-photon emission computed tomography/computed tomography revealed focally increased methylene diphosphonate uptake in the right femoral condyle, possibly due to osteolysis (Figure 3). This patient was diagnosed with wear of the PE and subsequent catastrophic failure of the femoral component.

One-stage revision surgery was performed using a standard medial parapatellar approach. Severe black metallosis was found intraoperatively within the lining of the joint, suggesting the release of metallic debris from the prosthesis (Figure 4). The medial side of the PE had completely worn off, resulting in the erosion of the femoral component from contact with the tibial tray, as evidenced by grooving with exposure of the underlying silver layers without black appearance. Moreover, the tibial component showed black staining from the metallic debris and groove along the posteromedial aspect of the titanium tibial component and thinning of the peripheral locking mechanism (Figure 5). Metallic debris was also noted within the cut surface of the femur and tibia, indicative of the osteolysis that had occurred, leading up to the failure of the implants. All the components were removed, and synovectomy was done as much as possible; however, complete resection of debris was impossible due to the potential risk of neurovascular injury. Revision TKA was performed using the semi-constrained Constrained condylar Knee (CCK) (LCCK [Legacy Constrained Condylar Knee]; Zimmer, Warsaw, Ind, USA) (Figure 6). Metal augmentation was used on the distal and posterior condyles of the femur to fill the bone defect. She

HIGHLIGHTS

- Oxidized zirconium (Oxinium) has been shown to be an effective bearing surface for total knee arthroplasty (TKA) and an alternative material for use in patients with metal hypersensitivity.
- This case report describes a patient who experienced catastrophic failure of oxidized zirconium TKA with resulting accelerated wear and metallosis due to the metallic wear particles, resulting in a peculiar arthrogram appearance on the plain radiographs.
- Early identification of polyethylene wear and prompt revision are crucial to avoid the rapid progression of subsequent metallosis and catastrophic implant failure, particularly when using oxidized zirconium components for TKA.

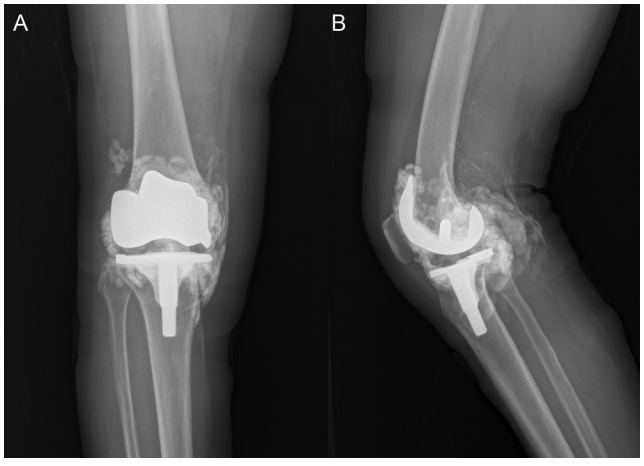

Figure 2. Postoperative anteroposterior (A) and lateral (B) radiographs of a failed oxidized zirconium total knee arthroplasty 12 years after index surgery with the grooving of the medial femoral condyle and the large metal arthrogram.

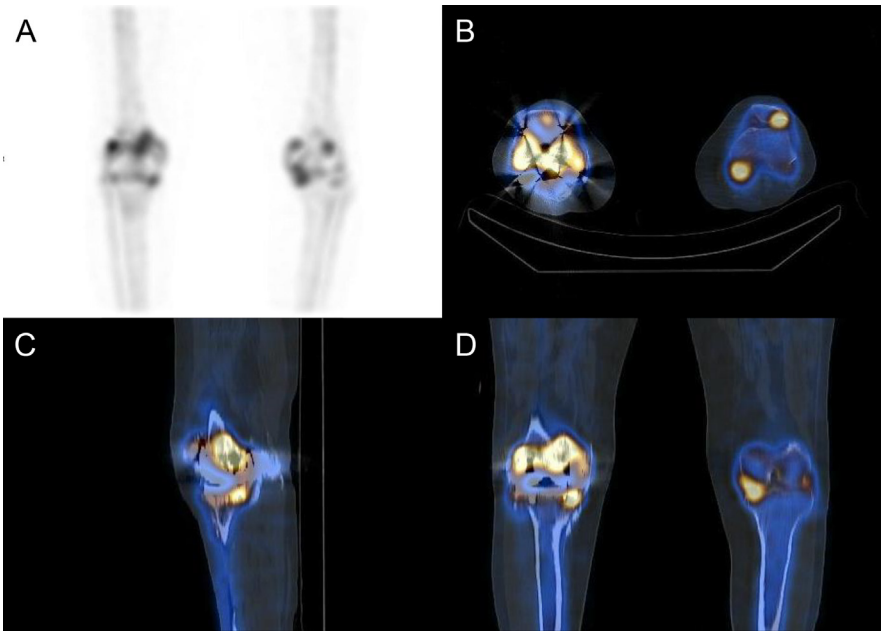

Figure 3. Bone scintigraphy and single-photon emission computerized tomography/computerized tomography A) coronal maximum intensity projection image; B) transaxial image; C) sagittal image; D) coronal image] of a failed oxidized zirconium total knee arthroplasty showed focally methylene diphosphonate uptake in the right femoral condyle, which was possibly due to osteolysis.

had no postoperative complications and demonstrated an improvement in clinical outcomes with good alignment and no evidence of osteolysis or loosening 2 years after the revision surgery.

Histopathological examination demonstrated widespread deposition of black-pigmented metal particles in periprosthetic synovial tissue (Figure 7). The synovium was reactive and chronically inflamed, apparently due to extensive deposits of fine black metal fragments. Infiltration of histiocytes and the formation of giant cells, a response to foreign substances, were observed in addition to phagocytosis of the black-pigmented metal (Figure 8).

This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of Hwasun Chonnam National University Hospital approved this study. Written informed consent was obtained from the patient to report this case (CNUHH–2022–219).

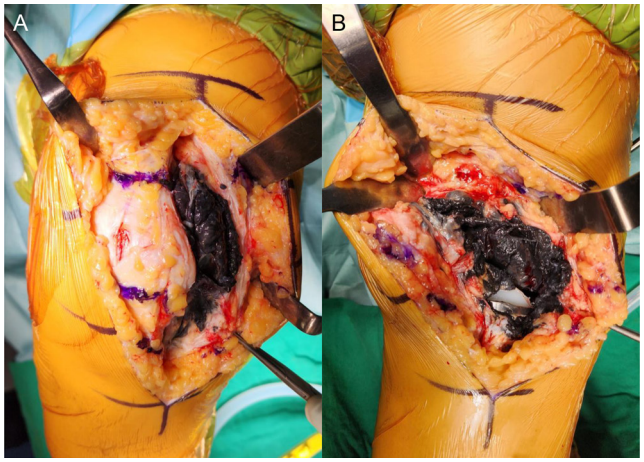

Figure 4. (A-B) Intraoperative photographs with severe black metallosis within the knee joint's synovial lining suggest implant failure due to extensive wear.

Discussion

This case demonstrates a unique case of metallosis because of the wear particles of a failed Oxinium femoral component based on the clinical and histologic findings. Our findings suggest that the formation of the peculiar radiographic finding resembling an "arthrogram" indicates the presence of oxidized zirconium debris in the synovium. Therefore, early recognition is crucial to prevent subsequent catastrophic implant failure.

In the present case, there were no abnormal findings of implant failure until 5 years after index surgery. However, at 10 years after primary TKA, radiographs demonstrated a TKA with obliteration of the PE space on the medial space with apparent grooving of the medial femoral condyle. The resultant severe metallosis was caused by friction between the femoral and tibial prosthetic metal surfaces due to catastrophic wear of the tibial PE. Then, zirconium deposits in the synovium gave an appearance similar to that of an arthrogram. These were derived from the wear and grooving of the Oxinium femoral component against the titanium tibial base plate. "Oxinium Arthrogram" of the surrounding prosthetic joint tissue, which is a sign of oxidized Zirconium implant failure, had grown and worsened further at 12 years after TKA. Early identification of PE wear and prompt revision could have avoided the rapid progression of the subsequent metallosis and catastrophic implant failure.

Oxidized zirconium was introduced as an alternative bearing surface with ceramic properties of lower coefficient of friction, fracture resistance properties of metal, and higher resistance to scratching, leading to decreased formation of wear particles. Despite this, there has been evidence of wear and metallosis after oxidized zirconium TKA.[9,10,12] Frye et al[9] reported 1 TKA and 1 THA (total hip arthoplasty) with Oxinium components, which failed with the subsequent appearance of an arthrogram on the plain radiograph, consistent

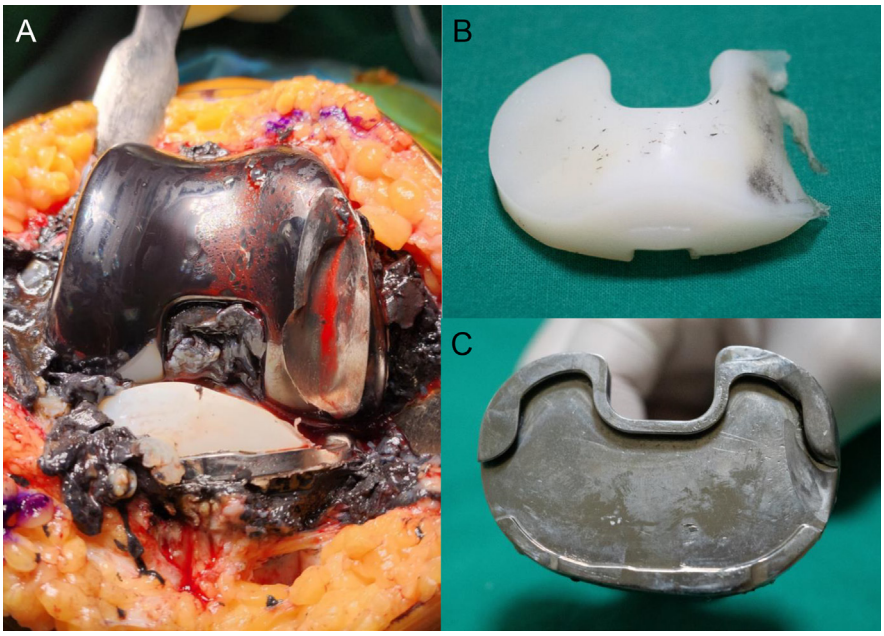

Figure 5. (A) Intraoperative photographs with extensive wear and significant grooving of the femoral component with exposure to the underlying zirconium substrate and (B) the complete wear of the medial side of polyethylene. (C) Explanted total knee arthroplasty tibial component with black staining from the oxidized zirconium debris and groove along the posteromedial aspect of the titanium tibial component.

with the findings of our case. They showed the femoral component with visible wear and exposed the underlying zirconium substrate of the underlying oxidized layer. Both cases of TKA (the PE was completely worn through in the knee) and THA (hip PE liner had dissociated from the cup) had "Mode 2" wear.[13] In comparison, Kore et al[10] have reported a similar oxidized zirconium TKA failure with no radiographic signs of an arthrogram or hardware failure. They showed identical findings of wear and scratches of the femoral component, albeit much less abrasive than those of Frye et al,[9] which may be the cause of the arthrogram appearance on radiographs.

Metallic-wear debris is a well-known entity resulting from complications of arthroplasties.[14] The complications of this debris range from serum elevation of metal ion concentration to pseudotumor. Although some metallosis cases have radiographic findings of prosthesis loosening and soft tissue swelling, striking radio-opacities of the joint synovium and capsule are not specific features. Polyethylene debris, polymethylmethacrylate, and metal debris are known to cause osteolysis[15] due to the immune response to the metallic particles and release of cytokines and inflammatory cells.[16]

By comparison, the failure of the Oxinium component in our case and the few others discussed previously demonstrate the prominent formation of an arthrogram.[8,9] Kop et al[17] proved that the underlying zirconium alloy core is a softer metal than titanium and remains soft after oxidation, lending itself to plastic deformation, progressive wear, and metallosis if left exposed.[17] Subluxation or dislocation of the replaced joint can lead to friction between unintended articulating surfaces, and damage to the thin oxidized surface may expose the deeper layers of non-oxidized zirconium, which may lead to an adverse tissue reaction.

Metallosis is observed histologically as extensive fibrosis with characteristic dark pigment deposition of wear-induced particles and

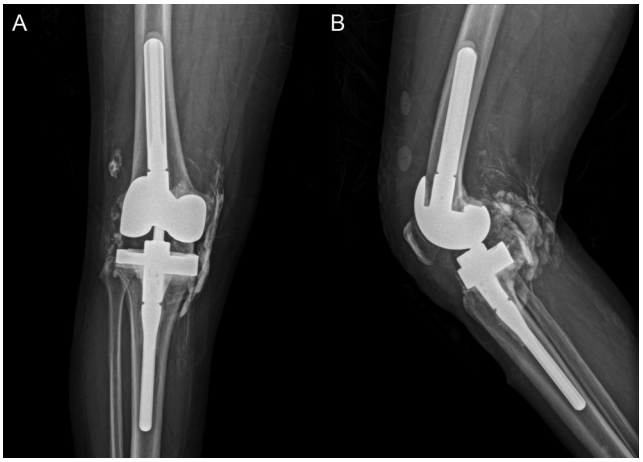

Figure 6. Postoperative anteroposterior radiograph (A) and lateral radiographs (B) after synovectomy and revision total knee arthroplasty. Metal augmentation was used on the distal and posterior condyles of the femur to fill the bone defect.

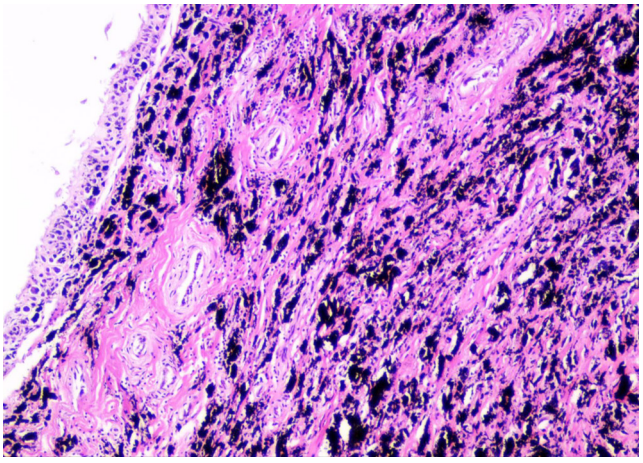

Figure 7. Representative photomicrograph of the histopathologic examination showing periprosthetic metallosis and metal-induced synovitis. The synovium is reactive and appears loaded with fine black metallic debris (hematoxylin and eosin, ×100).

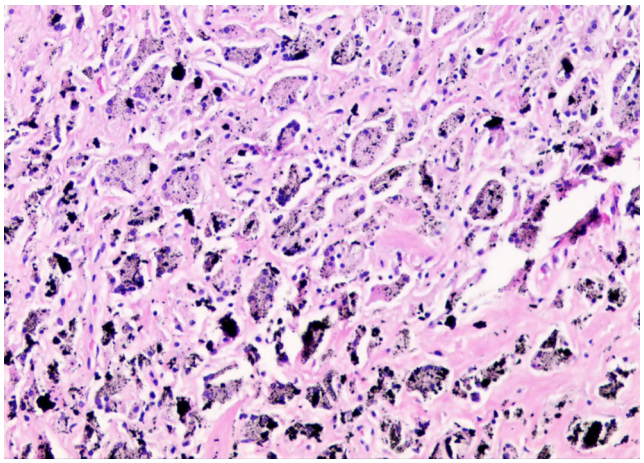

Figure 8. High-power magnification showed the presence of black metallic debris within multinucleated giant cells in the synovial lining (Congo red, 200×).

the presence of histiocytes, including macrophages, dendritic cells, Langerhans cells, and multinucleated giant cells. Once the inflammatory cascade has been started, macrophages continue to indirectly cause osteolysis by releasing chronic inflammatory mediators and by the activation of the RANK/RANKL (receptor activator of nuclear factor-κB/receptor activator of nuclear factor-κB ligand) pathway, which in turn manifests further failure of the implant.[18] In the present study, we used pathologic findings to prove that the metallosis resulted from the wear of the failed oxidized zirconium implant and tibial PE. However, histologically, oxidized zirconium metallosis is not significantly different from metallosis caused by other factors, and the differentiation between oxidized zirconium and other metallic debris and/or corrosion products can be very difficult at conventional microscopic examination, especially if mixed in the macrophagic cytoplasm, and elemental composition analysis is required for definite characterization.[19] Due to the limited generalizability in the case report, further larger studies are needed to elucidate the different histologic findings seen in oxidized zirconium implants.

The present case of failed oxidized zirconium TKA has 3 significant points. First, the distinct arthrogram appearance on radiographs can be an alarming sign of rapidly worn, oxidized zirconium and failed implant, necessitating revision surgery. Second, even if the component is fixed with good alignment, close observation and diagnosis of the PE wear with follow-up imaging are essential to prevent the rapid progression of subsequent metallosis and osteolysis. Third, surgeons must take care during the implantation of the component and cementing not to violate the oxidized zirconium surfaces free of their black oxidized layer in the femoral component. In retrospect, serial radiographs could have revealed early clues of PE wear and subsequent metallosis, especially when she first presented with knee instability at 10 years after the index surgery, which was most likely due to attenuation of the normal ligament tension of the knee due to the loss of the PE height.

Conclusion

Despite the proposed benefits of oxidized zirconium, surgeons need to be mindful of the possibility of catastrophic wear of the Oxinium, which can lead to exposure of the underlying layer. This can generate the risk of accelerated wear, deformation, and metallosis with the resultant appearance of an arthrogram on plain radiographs; thus, patients, especially with painful, malaligned implants, should be intently monitored clinically and radiographically. Early identification of PE wear and prompt revision are crucial to avoid the rapid progression of subsequent metallosis and catastrophic implant failure, particularly when using oxidized zirconium components for TKA. Further study with a more extended follow-up period is needed to ensure the safety and effectiveness of oxidized zirconium implants.

Ethics Committee Approval: This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of Hwasun Chonnam National University Hospital approved this study (Approval No: CNUHH-2022-219, Date: November 21, 2022).

Informed Consent: Informed consent was obtained from the patient.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – H.Y.Y., J.K.S.; Design – H.Y.Y., J.K.S.; Supervision – H.Y.Y.; Resources – H.Y.Y., J.K.S.; Materials – H.Y.Y., J.K.S.; Data Collection and/or Processing – K.A.A., M.G.N.; J.H.C.; Analysis and/or Interpretation – J.K.S., K.A.A., M.G.N.; J.H.C.; Literature Search – J.K.S., K.A.A., M.G.N.; Writing Manuscript – J.K.S.; Critical Review – H.Y.Y.

Declaration of Interests: The authors declare that they have no conflict of interest.

Funding: This work was supported by the Korea Medical Device Development Fund grant funded by the Korean government (The Ministry of Science and ICT, The Ministry of Trade, Industry and Energy, The Ministry of Health & Welfare, The Ministry of Food and Drug Safety) (Project Number: 9991007120, KMDF_PR_20200901_0038).

References

1. Emmerson KP, Moran CG, Pinder IM. Survivorship analysis of the kinematic stabilizer total knee replacement: a 10- to 14-year follow-up. *J Bone Joint Surg Br*. 1996;78(3):441-445. [CrossRef]
2. Ranawat CS. History of total knee replacement. *J South Orthop Assoc*. 2002;11(4):218-226.
3. Laskin RS. An oxidized zr ceramic surfaced femoral component for total knee arthroplasty. *Clin Orthop Relat Res*. 2003;416(416):191-196. [CrossRef]
4. Heyse TJ, Haas SB, Efe T. The use of oxidized zirconium alloy in knee arthroplasty. *Expert Rev Med Devices*. 2012;9(4):409-421. [CrossRef]
5. Lachiewicz PF, Watters TS, Jacobs JJ. Metal hypersensitivity and total knee arthroplasty. *J Am Acad Orthop Surg*. 2016;24(2):106-112. [CrossRef]
6. Vivegananthan B, Shah R, Karuppiah AS, Karuppiah SV. Metallosis in a total knee arthroplasty. *BMJ Case Rep*. 2014;2014. [CrossRef]
7. Sharareh B, Phan DL, Goreal W, Schwarzkopf R. Metallosis presenting as knee pain 26 years after primary total knee arthroplasty. *J Orthop Case Rep*. 2015;5(2):62-65. [CrossRef]
8. Greco N, Berend K. Polyethylene liner dislocation of fixed-bearing medial oxinium unicompartmental arthroplasty with severe metallosis. *Knee*. 2018;25(2):341-345. [CrossRef]
9. Frye BM, Laughery KR, Klein AE. The oxinium arthrogram: a sign of oxidized zirconium implant failure. *Arthroplast Today*. 2021;8:103-109. [CrossRef]
10. Kore L, Bates T, Mills G, Lybeck D. Oxidized zirconium total knee arthroplasty implant failure in a patient with knee instability. *Arthroplast Today*. 2020;6(3):552-555. [CrossRef]
11. Parvizi J, Zmistowski B, Berbari EF, et al. New definition for periprosthetic joint infection: from the workgroup of the musculoskeletal infection society. *Clin Orthop Relat Res*. 2011;469(11):2992-2994. [CrossRef]
12. Patel AM, Spector M. Tribological evaluation of oxidized zirconium using an articular cartilage counterface: a novel material for potential use in hemiarthroplasty. *Biomaterials*. 1997;18(5):441-447. [CrossRef]
13. McKellop HA. The lexicon of polyethylene wear in artificial joints. *Biomaterials*. 2007;28(34):5049-5057. [CrossRef]
14. Lombardi AV, Barrack RL, Berend KR, et al. The hip society: algorithmic approach to diagnosis and management of metal-on-metal arthroplasty. *J Bone Joint Surg Br*. 2012;94(11):14-18. [CrossRef]
15. Gallo J, Goodman SB, Konttinen YT, Wimmer MA, Holinka M. Osteolysis around total knee arthroplasty: a review of pathogenetic mechanisms. *Acta Biomater*. 2013;9(9):8046-8058. [CrossRef]
16. Purcell A, Buckner S, Brindley G, Grimes J. A unique case of extra-articular extravasation of metal into the lower leg resulting from oxidized zirconium wear particles from total knee arthroplasty. *Arthroplast Today*. 2020;6(4):988-992. [CrossRef]
17. Kop AM, Whitewood C, Johnston DJ. Damage of oxinium femoral heads subsequent to hip arthroplasty dislocation three retrieval case studies. *J Arthroplasty*. 2007;22(5):775-779. [CrossRef]
18. Bitar D, Parvizi J. Biological response to prosthetic debris. *World J Orthop*. 2015;6(2):172-189. [CrossRef]
19. Krenn V, Perino G. Histological diagnosis of implant-associated pathologies. In: *Histological Diagnosis of Implant-Associated Pathologies*. Berlin, Heidelberg: Springer Berlin Heidelberg; 2017:1-44.