

Severe Wear and Metal Poisoning in Revision Surgery after Ceramic Fracture Treated with Dual Mobility Prosthesis

J. E. GARCIA-RELLAN¹, A. SUBIAS LOPEZ¹, E. GUILLEN BOTAYA¹, A. SILVESTRE MUÑOZ²

¹University Clinical Hospital of Valencia, Spain; ²University of Valencia, Department of Surgery, Spain.

Correspondence at: José E GARCIA-RELLAN MD, PhD, Avda Blasco Ibanez 11, 46010 Valencia, Spain. E-mail: josemmensualgr@gmail.com

The aim of this study was to analyze the outcomes of revision surgery for a broken ceramic when using a dual-mobility (DM) implant with a metallic inner head (CoCr). A retrospective analysis was conducted on 225 cases utilizing DM implants to evaluate complications. In cases where DM was used to treat a prior ceramic fracture, we assessed clinical outcomes, wear patterns, and metal-ion levels. Three cases requiring revision after ceramic fracture presented accelerated wear and marked metal-ion elevations, leading to significant morbidity and mortality. Metal debris and ceramic fragments were observed embedded in the polyethylene surfaces of the implants, particularly affecting the metal heads. Symptoms of systemic metal toxicity included fatigue, anorexia, auditory and visual symptoms, and cardiac complications. The use of DM prostheses following ceramic fractures poses significant risks of accelerated wear and metal poisoning. Notably, wear is much more pronounced in the internal metal head than in the insert. Clinical vigilance is essential to detect and manage complications promptly. After meticulous debridement, ceramic-on-ceramic or ceramic-on-polyethylene remain reasonable alternatives; our findings should not be generalized to standard DM applications.

Keywords: Dual mobility, Ceramic fracture, Accelerated wear, Metal poisoning.

INTRODUCTION

The use of dual mobility (DM) in hip arthroplasty prevents prosthetic instability issues. This technology is particularly useful in cases where the risk of dislocation is increased, or in cases of revision surgery^{1,5}. However, DM presents specific complications such as intraprosthetic dislocations^{6,7}, increased wear^{8,9} or corrosion^{8,10,11}.

Third-body wear is a known complication in hip prosthetic surgery¹², especially in revision surgeries after a ceramic fracture. Despite proper cleaning and synovectomy of the joint in revision surgery, microscopic ceramic fragments remain in the joint, causing wear problems¹³. Initially, metal-on-polyethylene (MoP) pair was used in the revision surgery of a broken ceramic^{14,15}, but its use was associated with massive metal wear and cobalt intoxication^{15,17}.

To date, there are no studies that meticulously analyze the corrosion produced in DM implants when

used in revision surgery for a broken ceramic. The objective of the present study is to analyze third-body wear produced in DM implants in revision surgeries after a broken ceramic, survival until replacement, its clinical implications, and its failure mechanism.

MATERIAL AND METHODS

A retrospective review of all DM implants used in our service from January 2013 to January 2022 was conducted. Ethics approval was granted by the Clinical Research Ethics Committee of the University Clinical Hospital of Valencia (2024/212) and conducted in accordance with the Declaration of Helsinki. Written informed consent for publication of clinical details/images was obtained from all patients (and from next of kin for the deceased). A total of 225 dual mobility implants were performed, with a mean follow-up of 37.2 months. The reasons for the use of DM were analyzed (Table I). Of the initial 225 cases,

Table I. — Reasons for using dual mobility. Percentages calculated over the total cohort (N = 225).

	n	%	
Primary cases			
Primary osteoarthritis		23	10,2
Femoral neck fracture		49	21,8
Avascular necrosis	4	1,8	
Tumor	9	4,0	
Acetabular fracture	7	3,1	
Failed osteosynthesys	9	4,0	
Conversion of hip arthrodesis	4	1,8	
Revision cases			
Instability	32	14,2	
Aseptic loosening	40	17,8	
Second-stage after PJI	41	18,2	
Ceramic fracture	3	1,3	
Periprosthetic fracture	4	1,8	
Total	225	100,0	

105 were primary procedures (native hips) and 120 were used in revision surgeries. Among revision cases, three (1.3%) were performed following a fracture of a ceramic component. These three cases constitute the focus of the present report. A patient flow diagram (Fig. 1) summarizes case selection and follow-up.

In cases where DM components were used following ceramic fracture, the time from arthroplasty to diagnosis of massive wear, levels of metal-ions at the time of diagnosis, and clinical implications of metal intoxication were studied. Upon prosthetic revision of DM due to wear, a study of the components used was conducted¹².

Retrieval analysis and damage grading

Explanted components were inspected visually and under stereomicroscopy (10×–40×), and representative areas were photographed with scale bars. For each dual-mobility construct we evaluated: (i) the inner metallic head, (ii) the metallic insert, (iii) the polyethylene (PE) head (external and internal bearing surfaces), and (iv) the taper. Surfaces were divided into zones for zone-by-zone scoring: polar/dome, equatorial, and rim for the PE head (internal and external) and for the inner metallic head; articular face and peripheral rim for the metallic insert; and the contact area for the taper. The damage-mode taxonomy and mapping were adapted from prior DM retrieval work and polyethylene damage assessments^{12,18,19}.

For polyethylene, we used the fixed-order acronym SPBADDE (Scratching, Pitting, Burnishing, Abrasion,

Delamination, Deformation–Ovalization, Embedded debris). Each mode was graded on a 0–3 semi-quantitative scale (0 = none, 1 = mild, 2 = moderate, 3 = severe), and cells report values in SPBADDE order; when needed, the sum (Σ) of the seven scores is provided to convey overall zonal burden (range 0–21)^{12,18,19}.

For metallic bearing surfaces (inner metallic head and metallic insert), we used the fixed-order acronym SPBGDCM (Scratching, Pitting, Burnishing, Gouging, Deformation (plastic), Corrosion staining, Material loss). S, P, B, G, D, C were graded 0–3 (0–3 as above). Material loss (M) was recorded as present/absent (optionally with a qualitative note, e.g., linear depth), consistent with prior DM retrieval descriptions of surface damage and modular interface corrosion^{8,12,19}.

For the taper (trunnion), overall fretting–corrosion severity was summarized using the Goldberg score (1–4), a multicenter retrieval standard for modular hip tapers^{12,20}. Where volumetric measurement was not feasible, a semi-quantitative description was provided; where feasible, linear depth of wear features was recorded as a proxy^{8,12,19}.

Metal ion analysis

Blood samples for cobalt and chromium determination were analyzed in the hospital’s Toxicology Laboratory under the section “trace elements.” Quantification was performed using inductively coupled plasma mass spectrometry (ICP–MS). For cobalt, samples were obtained from whole blood collected in EDTA

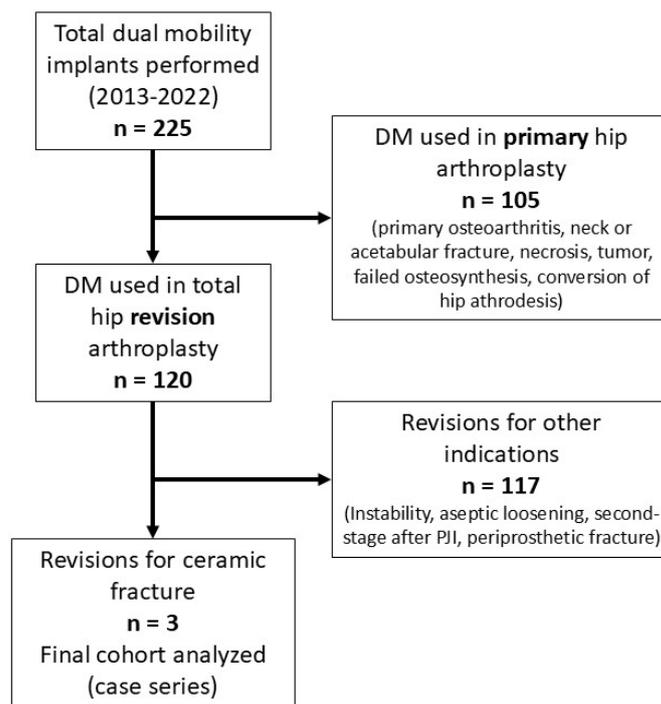


Fig. 1 — Flow diagram summarizing patient selection and study cohort.

tubes, and for chromium, from plasma samples. The reference values established by the laboratory were $< 1 \mu\text{g/L}$ for cobalt in blood and $< 2 \mu\text{g/L}$ for chromium in plasma. Samples were processed immediately after collection to minimize contamination, and results were expressed in micrograms per liter ($\mu\text{g/L}$). Serial measurements were performed, when possible, to monitor the evolution of metal levels after prosthetic removal or chelation therapy.

RESULTS

Among the 225 DM implants performed between 2013 and 2022, three cases (1.3%) were revised after a ceramic fracture and received a DM construct with a metallic inner head. Ceramic fractures occurred a mean of 55 months after the index THA (range, 31–125 months) after the initial surgery, and revision with a DM prosthesis featuring a metal inner head was performed. Revision was performed a mean of 12 days after diagnosis (range 11–13), involving debridement, extensive synovectomy, joint lavage, and cup replacement using a modular DM prosthesis. All three cases evolved to accelerated inner-bearing wear with marked cobalt elevations. The mean age of patients at the time of diagnosis of systemic metal toxicity was 62 years (range 54 to 75 years).

Case 1 involved a 64-year-old man who had previously undergone a primary ceramic-on-ceramic THA using

a Quadra-H femoral stem and Versafit-CC acetabular cup (Medacta, Castel San Pietro, Switzerland) for avascular necrosis. At 125 months post-index surgery he experienced a ceramic liner fracture after a sports-related cracking episode (Fig 2A). He was revised to a modular G7 dual-mobility (DM) cup (Zimmer Biomet, Warsaw, IN, USA) with a cobalt–chromium inner head, together with extensive debridement, synovectomy, copious lavage, and cup exchange within roughly two weeks from diagnosis. Over the subsequent 7–8 months, he developed weight loss, asthenia, anorexia, hyperglycaemic decompensation, a pulmonary embolism, and progressive auditory and visual complaints. At toxicity diagnosis, whole-blood cobalt was $1308 \mu\text{g/L}$ and chromium in plasma $17 \mu\text{g/L}$. The construct was removed (Fig 2B) with aggressive soft-tissue debridement and disodium calcium edetate (EDTA) chelation was administered. Postoperative follow-up was satisfactory, and blood metal levels decreased. Table II depicts the evolution of metal levels over time. Table III summarizes the serial ion concentrations, time from revision to diagnosis, main clinical symptoms, chelation therapy, and clinical outcomes. The patient declined a planned second-stage reimplantation. Hearing partially improved, while visual toxicity persisted with bilateral absolute scotoma and macular atrophy. Representative microphotographs are provided in Figures 5A–C, and wear grading is summarized in Table IV.

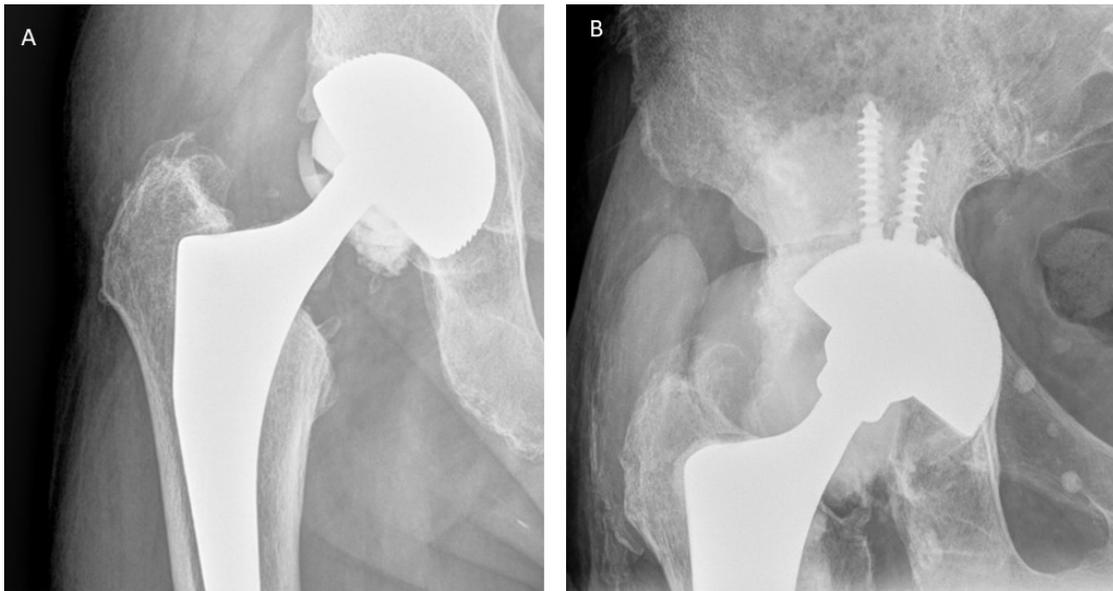


Fig. 2

Table II. — Cobalt and chromium levels.

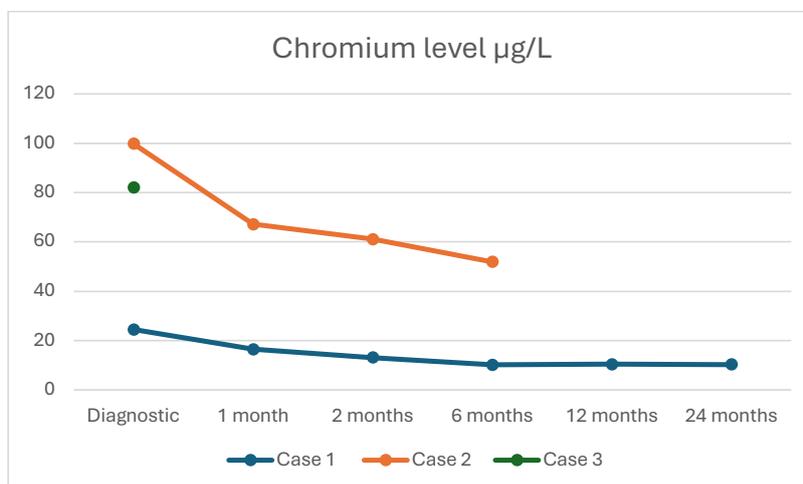
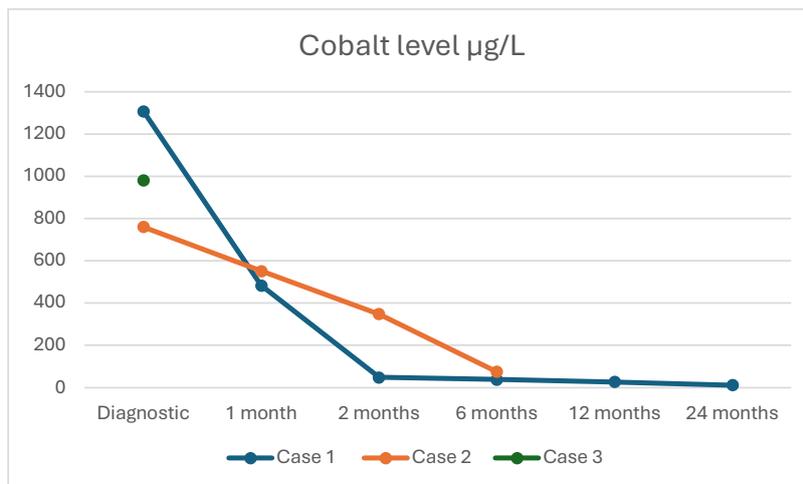


Table III. — Serial cobalt (blood) and chromium (plasma) levels, main symptoms, and clinical outcomes.

Case	Cobalt in blood (µg/L)	Chromium in plasma (µg/L)	Time from revision to diagnosis (months)	Key clinical symptoms	Chelation therapy	Final outcome
1	1308 → 315 → 85	17 → 7 → 3	8	Fatigue, anorexia, hearing loss, visual impairment, pulmonary embolism	EDTA chelation	Partial recovery of hearing; persistent visual loss
2	760 → 280 → 64	100 → 42 → 8	24	Tinnitus, dizziness, myocardial infarction, decreased visual acuity	EDTA chelation	Cochlear implant; moderate residual visual loss
3	980	82	49	Hearing loss, pericardial effusion, cardiac failure	—	Death due to heart failure

Reference values: cobalt < 1 µg/L (blood), chromium < 2 µg/L (plasma); *EDTA = disodium calcium edetate.

Table IV. — Zone-by-zone semi-quantitative damage grading of retrieved components.

Component / Zone	Damage mode (fixed order)	Case 1	Case 2
PE head – External surface: Pole	SPBADDE*	1 / 3 / 0 / 1 / 0 / 0 / 3 Σ=8	2 / 1 / 1 / 0 / 0 / 0 / 1 Σ=5
PE head – External surface: Equator	SPBADDE*	2 / 3 / 0 / 0 / 0 / 0 / 3 Σ=8	2 / 1 / 1 / 0 / 0 / 0 / 2 Σ=6
PE head – External surface: Rim	SPBADDE*	0 / 1 / 0 / 0 / 0 / 0 / 1 Σ=2	2 / 1 / 1 / 0 / 0 / 0 / 1 Σ=5
PE head – Internal surface: Pole	SPBADDE*	1 / 3 / 0 / 1 / 0 / 0 / 3 Σ=8	0 / 1 / 1 / 0 / 0 / 0 / 1 Σ=3
PE head – Internal surface: Equator	SPBADDE*	1 / 3 / 0 / 1 / 0 / 0 / 3 Σ=8	1 / 1 / 1 / 0 / 0 / 0 / 3 Σ=6
PE head – Internal surface: Rim	SPBADDE*	0 / 1 / 0 / 0 / 0 / 0 / 1 Σ=2	0 / 1 / 0 / 0 / 0 / 0 / 1 Σ=2
Inner metal head – Pole/Dome	SPBGDCM**	3 / 2 / 0 / 1 / 0 / 2 ML: present	3 / 1 / 0 / 0 / 0 / 1 ML: present
Inner metal head – Equator	SPBGDCM**	3 / 1 / 0 / 0 / 0 / 1 ML: absent	3 / 1 / 0 / 0 / 0 / 1 ML: absent
Inner metal head – Flange	SPBGDCM**	2 / 0 / 0 / 0 / 0 / 0 ML: absent	3 / 0 / 0 / 0 / 2 / 0 ML: absent
Metal insert – Articular face	SPBGDCM**	0 / 0 / 1 / 0 / 0 / 0 ML: absent	0 / 0 / 1 / 0 / 0 / 0 ML: absent
Metal insert – Rim	SPBGDCM**	1 / 0 / 1 / 0 / 0 / 0 ML: absent	0 / 0 / 0 / 0 / 0 / 0 ML: absent
Taper	Goldberg	Goldberg = 3 (moderate)	Goldberg = 2 (mild)

Case 2 was a 55-year-old woman who had received a primary ceramic-on-ceramic THA with an Aelton femoral stem (Exactech, Gainesville, FL, USA) at another institution and soon after presented instability. At cup-only revision, a minimal posterior-edge microfracture of the ceramic insert due to neck impingement was identified (Fig 3A). The acetabulum was revised to a modular G7 DM cup (Zimmer Biomet) with a cobalt–chromium inner head, following capsular debridement. Within 3–4 months she developed nausea, vomiting, tinnitus, and dizziness, followed at month 4 by an acute myocardial infarction and later a decline in visual acuity. At 24 months after the DM revision, she underwent re-revision with removal of the construct (Fig 3B and 3C), extensive debridement, implantation of a new ceramic-on-ceramic bearing, and EDTA chelation. Metal-ion concentrations at diagnosis were cobalt 760 µg/L and chromium 100 µg/L, declining after treatment (Tables II and III). Despite a satisfactory postoperative course, she required a cochlear implant for severe sensorineural hearing loss and retained moderate visual impairment. Microphotographs are shown in Figures 6A–C, with damage characterization detailed in Table IV.

Case 3 concerned a 54-year-old man with bilateral THAs for alcohol-related avascular necrosis, both implanted with a Quadra-H stem and Versafit-CC cup (Medacta) via an anterior approach. A left ceramic liner fracture occurred 9 years after implantation following a fall (Fig 4A). The acetabulum was exchanged to a modular G7 DM cup (Zimmer Biomet) with a cobalt–chromium inner head. Approximately 2 years later he reported progressive hearing loss, and in the ensuing months developed severe cardiac complications with pericardial effusion and systolic dysfunction requiring intensive care. CT demonstrated a radiopaque periprosthetic collection extending to the retro-trochanteric region and the iliacus (Fig 4B and 4C). At toxicity diagnosis, cobalt in blood measured 980 µg/L and chromium in plasma 82 µg/L. Revision surgery was proposed but not undertaken due to critical cardiac status, and the patient died from heart failure.

Retrieval findings

Wear characterization is detailed in Table IV (zone-by-zone grading). Microphotographs for Case 1 are shown in Figures 5A–C, and for Case 2 in Figures 6A–C.

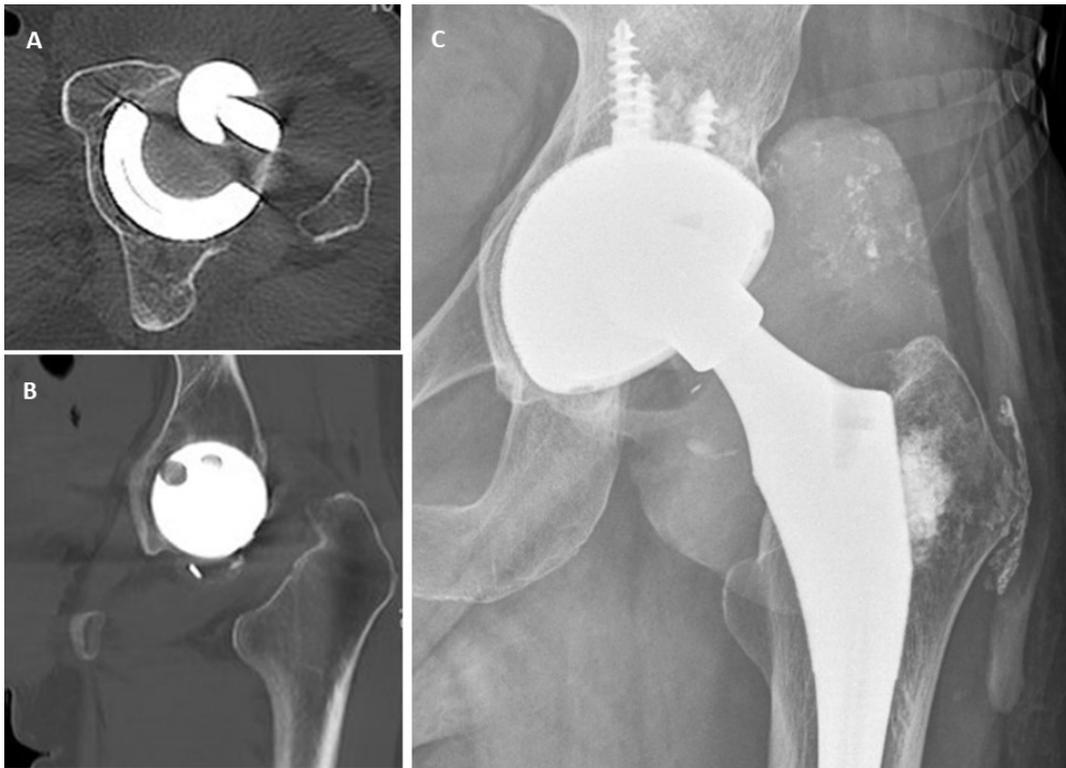


Fig. 3

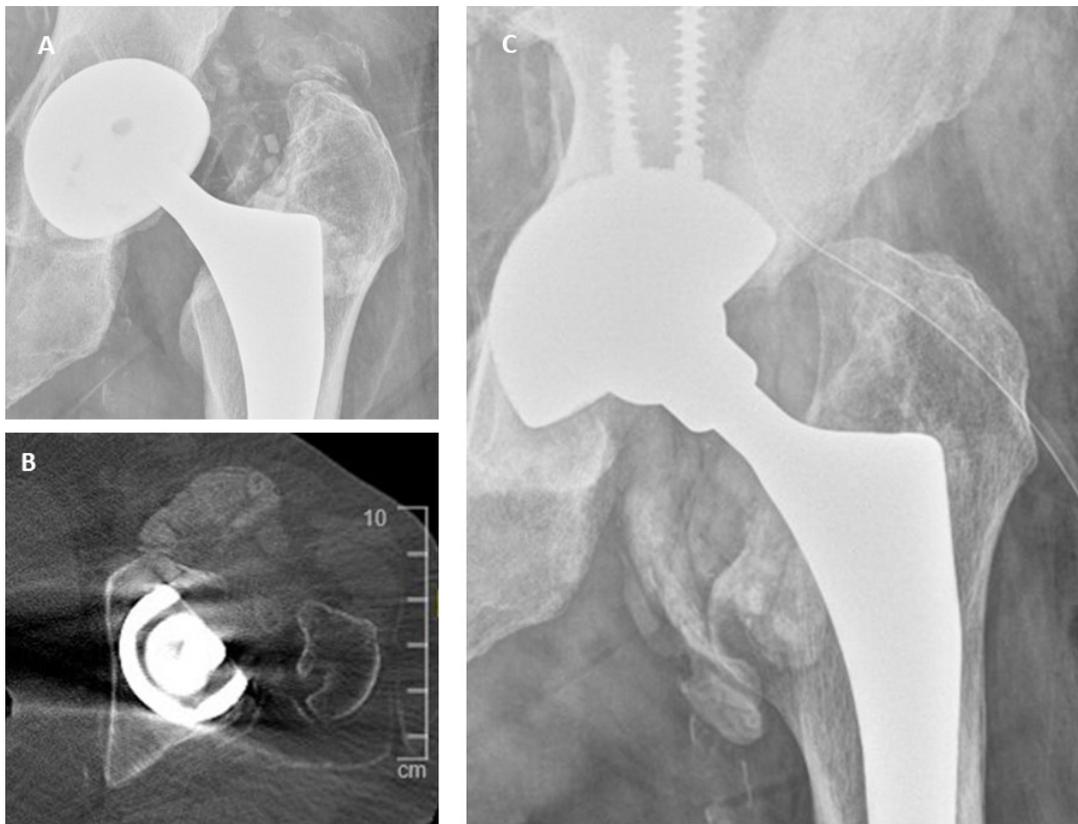


Fig. 4

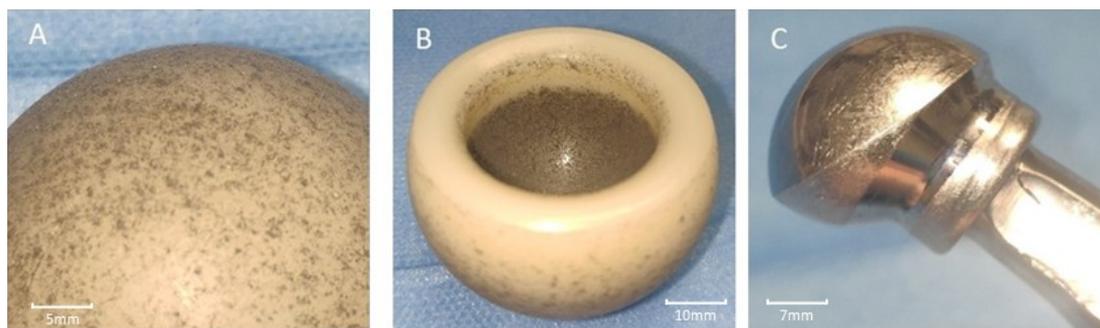


Fig. 5

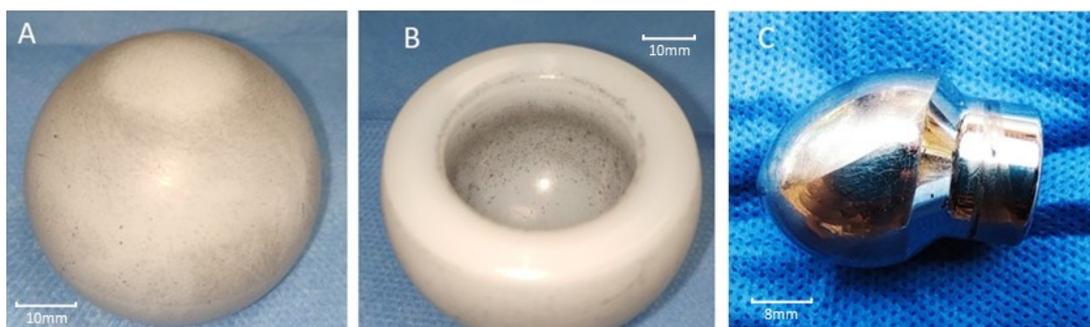


Fig. 6

DISCUSSION

The main finding of our study is that all cases in which a modular DM construct with a metallic inner head was used after a ceramic fracture have presented complications, resulting in the death of one patient and requiring repeated revision in the other two patients.

Our findings should be interpreted in the context of the broader dual-mobility (DM) literature. In contemporary series of standard DM constructs (i.e., not implanted after ceramic fracture), serum metal-ion concentrations are generally low, and clinically significant elevations are uncommon. Reports on modular DM have described isolated cases of corrosion and adverse local tissue reactions, but large cohorts typically show low median ion levels with only a small subset exhibiting outliers^{8,12}. These data support that elevated cobalt/chromium values are not inherent to DM designs per se.

Various studies have shown the outcomes of ceramic fracture revisions^{14,15,21}. The choice of friction pair to use after a ceramic fracture has been a subject of debate in recent years. Sharma¹⁴ found no revisions, osteolysis, or loosening in a series of 8 patients over 10 years where a metal-on-polyethylene (MoP) pair was used after a ceramic fracture. On the other hand, Allain et al¹⁵ reported a 63% survival rate after 5 years of a revision of a ceramic head fracture. The most popular bearing option after a ceramic fracture is a new CoC

pair, which has been shown to reduce wear from third-body wear in experimental studies^{21,22}. Zagra et al²³ suggest the use of CoP, because of the possible third body caused by retained ceramic fragments may be less harmful on a CoP surface.

To our knowledge, there are no studies analyzing the survival or function of revision after a ceramic fracture with DM implants. Micro ceramic fragments retained in the joint become embedded in the polyethylene on its surfaces, both internally and externally¹². This has been demonstrated in the analysis of the components in this study. Given the presence of these ceramic micro fragments in the polyethylene, accelerated wear by third-body wear of the metallic components of the DM prosthesis occurs¹². In our study, we have observed that this wear is much more pronounced in the metallic head than in the insert. This likely reflects delayed locking at the polyethylene–insert interface, increasing relative motion and wear at the polyethylene–inner head articulation¹⁹.

Signs and symptoms of systemic metal toxicity have preceded the diagnosis of wear. Bradberry et al²⁴ noted that cobalt and chromium levels in blood were much higher in the case of using a metal prosthesis after a ceramic fracture than in a MoM prosthesis, with greater clinical significance. The initial manifestations of metal intoxication are nonspecific. Fatigue, anorexia, and vomiting occur in the early stages of intoxication, along with hematological

(anemia) and endocrine (hypothyroidism) alterations. As cobalt levels increase, auditory symptoms due to neurotoxicity begin. These include tinnitus, vertigo, and decreased hearing. A higher degree of hearing loss has been associated with higher blood cobalt concentration levels, as well as partial or complete symptom improvement after prosthetic replacement²⁵. In our series, hearing loss was observed in all patients. Some improvement after replacement was also noted, although complete recovery was not achieved in any case. One patient, case 2, required a cochlear implant for improved hearing. Elevated cobalt levels also cause optic neurotoxicity. Alterations ranging from loss of contour sharpness and colours to nearly complete blindness have been described. Cobalt toxicity has been shown to cause retinopathy, optic atrophy with decreased evoked potential response, and retinal epithelial dysfunction²⁶. Visual acuity decrease was also detected in two cases (cases 1 and 2). The most serious complications of cobalt intoxication are cardiovascular. Complications such as exertional dyspnea, diastolic or systolic dysfunction, dilated cardiomyopathy, and pericardial effusions have been described²⁴. In our series, all cases presented some form of cardiac or vascular complication. Case 1 experienced a pulmonary embolism 6 months after prosthetic replacement. Case 2 suffered an acute myocardial infarction 4 months after replacement. In the third case, the patient developed pericardial effusion with myocardial damage and systolic dysfunction 49 months after replacement, and led to the patient's death. Unstable medical condition may affect the possibility of single-stage revision surgery.

Some authors have studied the presence of metallic debris in DM prostheses. It has been attributed to metallic particles originating from cup mobilization, loosening, screw abrasion, or impingement¹². The authors suggest that surgeons concerned about metallic embedded debris could use DM constructions with a ceramic inner head. DM after ceramic fracture warrants caution, even with a ceramic inner head, given that retained ceramic particles can embed on both polyethylene surfaces¹². Ceramic fragments embedded in the outer part of the polyethylene could result in insert wear, with a risk of systemic metal toxicity.

This study has several limitations. It is a retrospective review of a limited number of cases. However, it is a rare complication, so this case series may aid in initiating a designed study. It is the first case series of massive wear in DM prostheses due to third-body wear following ceramic fracture

reported in the literature. Patient follow-up is small for a study of outcomes in arthroplasty. However, the clinical and radiological implications are severe and rapidly apparent. The study's objective is not to analyze implant survival, but to show the clinical and radiological effects of accelerated wear, which become evident a few months after prosthetic replacement of the broken ceramic. Another study limitation is the reliance on available technology for analyzing extracted prosthetic components. Only two of the three implants with documented corrosion and systemic metal toxicity were available for retrieval analysis. However, the inability to study the implant in case 3 does not affect the recommendation to avoid the use of DM after a ceramic fracture. The greatest volumetric loss of metal was observed in the metal inner head. There are doubts as to whether the use of DM with a ceramic inner head would have been an acceptable option. Although there are no data for or against, it does not seem reasonable to use metallic component in DM constructs after a ceramic fracture, given that embedded debris has also been observed on the external surface of the polyethylene, in direct contact with the metal insert. These observations support avoiding CoCr inner heads in this context and favor CoC/CoP bearings after meticulous debridement and ion surveillance.

CONCLUSION

In ceramic-fracture revisions treated with a DM construct using a cobalt-containing inner head, we observed accelerated inner-bearing wear and marked cobalt elevations. These findings pertain to a specific high-risk scenario and should not be generalized to standard DM applications. After meticulous debridement and lavage, CoC or CoP bearings remain reasonable alternatives, with serial metal-ion monitoring.

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