Review

The Problem of Modular Hip Endoprosthesis

Dolinar Drago[1,2,3], Potparič Igor[1,2], Jenko Monika[3], Debeljak Mojca[4,5,6,*]

1. Department for Orthopaedic Surgery, University Medical Centre Ljubljana, Ljubljana, Slovenia
2. Medical Faculty, Chair for Orthopaedic Surgery, University of Ljubljana, Ljubljana, Slovenia
3. MD-RI Institute for Materials Research in Medicine, Ljubljana, Slovenia
4. University rehabilitation institute Republic of Slovenia Soča (URI Soča), Ljubljana, Slovenia
5. Faculty of Polymer Technology, Slovenj Gradec, Slovenia
6. Faculty of Health Sciences, University of Ljubljana, Ljubljana, Slovenia

* Correspondence: Igor Potparič igor.potparic@gmail.com

Abstract:
The mechanisms of premature fracture of modular-neck stems in two case studies: (I) when the neck and stem are both made of the same Ti6Al4V alloy, and (II) when the neck and stem are made from two different alloys, CoCrMo and Ti6Al4V alloy are presented. The study integrates two orthopedic patients who have undergone primary uncemented THA for usual indications in two orthopedic centers). Both centers are part of the national public health care system. Both surgeries were performed by two skilled orthopedic surgeons with more than 10 years of experience in THA. The survivorship of the modular neck of cast CoCrMo alloy was 24 months. The survivorship of the modular neck from Ti6Al4V alloy was 84 months. Advanced analyses were performed to assess the differences in the fretting, corrosion, and fatigue, using stereo light microscopy (SLM), scanning electron microscopy (SEM), X-ray energy-dispersive spectroscopy (EDS), and electron backscatter diffraction (EBSD). Patient demographic information, including sex, age, body mass index, survivorship of implants, and reason for the revision, was collected from medical records. The fretting and fatigue occurred on both modular stem retrievals, but the CoCrMo/Ti6Al4V alloy system suffered more corrosion due to additional galvanic corrosion and fractured earlier than the Ti6Al4V/Ti6Al4V metal alloy system. Both—metallic alloy systems used in this application are known to be highly corrosion-resistant, but the bio-tribo-corrosion processes need to be understood in detail and characterized so that appropriate improvements in design and materials can be made.

Keywords: Total hip arthroplasty; Modular neck; Ti6Al4V alloy; CoCrMo alloy; Corrosion

Citation: Dolinar D, Potparic I, Jenko M, Debeljak M. Problem of Modular Hip Endoprosthesis. Proceedings of Socratic Lectures. **2025**, 12, 41-45. https://doi.org/10.55295/PSL.12.2025.I5

1. Introduction

Modular neck stems were introduced to hip endoprosthesis with the expected benefits of reducing pain and improving the range of motion and leg length (Azar et al.,2016; Baleani et al., 2023; Ellma & Levine,2013). Besides classic stems, Wright Medical Technology/Microport, Stryker, Depuy, Lima Corporate, Zimmer, Adler Ortho, Cremasoli, and others are the recognized worldwide manufacturers of modular neck stems. The stems and the necks are available in different sizes and different neck angles, to tailor the implant to the individual patient. Increased implant modularity with modular necks made from Ti6Al4V and stems from the same alloy has generated interest in recent years because the various neck sizes, offsets, lengths, and design configurations allow the surgeon to optimize the range of motion and the patient's leg length. However, there have been concerns due to early *in vivo* fractures as well as adverse tissue reactions related to corrosion at the neck–stem interface (Baleani et al.,2023; Ellman & Levine, 2013; Wright et al., 2010; McTighe et al 2015; Park et al., 2018; Solarino et al., 2021; Maniscalco et al., 2020; Castagnini et al., 2023; Goffton et al., 2017; Fokter et al., 2017;).
The presence of the neck–stem interface using titanium alloys makes the neck junction vulnerable to fretting, corrosion, and fatigue fracture. Several authors reported an early fracture of long modular necks made of Ti6Al4V alloy (McTighe et al 2015; Park et al., 2018; Solarino et al., 2021;Maniscalco et al., 2020; Castagnini et al., 2023; Goffton et al., 2017; Fokter et al., 2017; Dolinar et al., 2018; Gorenšek & Jenko, 2018). Many of the femoral modular stems suffer from premature fractures after the total hip arthroplasty (THA) of the titanium alloy neck. Due to the results of *in vitro* investigations which presented better wear and mechanical properties, a cobalt–chromium–molybdenum neck was introduced (Castagnini et al., 2023; Goffton et al., 2017; Fokter et al., 2017; Dolinar et al., 2018; Jenko et al., 2018). CoCrMo neck fractures have also been reported after only a few months of implantation (Dolinar et al., 2018; Gorenšek & Jenko, 2018). Some reports have shown cases of fractured necks that could not be detracted from the stem pocket, requiring the replacement of the otherwise well-fixed femoral stems (Baleani et al.,2023; Wright et al., 2010; Solarino et al., 2021; Fokter et al., 2017;).
The main aim of our work was to investigate mechanisms of premature failure of two case studies due to the fracture of the long neck in two different metallic alloy systems: the same alloy (neck and stem are both made from the same Ti6Al4V alloy with a survivorship of 84 months) and different alloys (neck made from CoCrMo alloy with better mechanical properties and a stem body made from Ti6Al4V alloy, with a survivorship of only 24 months) (Dolinar et al., 2018; Jenko et al., 2018; Gorenšek & Jenko, 2018; Soteranos et al., 2013; Viceconti et al., 1997; Oladokun, et al., 2015; Gilbert et al., 1993). The research was a joint effort of orthopedic surgery clinicians and material scientists.

2. Methods

2.1. Stereo Light Microscopy (SLM)

A stereo light microscope, Tagarno FHD trend, was used for the visualization of the fractured surfaces of the Ti6Al4V modular neck and the Co-Cr-Mo modular neck.

2.2. Scanning Electron Microscopy (SEM, SEM/EDS, SEM/EBSD) Analysis

The morphology and microstructure of the fracture surfaces were analyzed using a scanning electron microscope, JEOL JSM 6500-F (JEOL Ltd., Japan). The SEM images were acquired using an accelerating voltage of 15 kV, with a current of about 500 pA and a working distance of 10 mm. Secondary electron and backscattered electron images were acquired. The elemental compositions of the samples were analyzed using Oxford INCA EDS analysis. The EDS spectra were acquired using a 15 kV and 1 nA beam, with an acquisition time of 60 s for each spectrum. The EDS spectra were analyzed using INCA Energy software to determine the elemental composition and distribution in the sample. Electron backscatter diffraction (EBSD) was also used to determine the type of carbides present in the microstructure. A Nordlys EBSD detector (HKL) and a Channel 5 data analysis suite were used. The EBSD patterns were acquired at 15 kV accelerating voltage and 2 nA current.

2. Results

Analysis of the surface and composition of the fractured surface of the two failed prostheses is shown in **Figures 1** and **2**. **Figure 1** presents the modular neck stem made of CoCrMo (neck) and /Ti6Al4V (stem) alloys and **Figure 2** presents the modular neck stem made of the same alloy: Ti6Al4V (neck) and Ti6Al4V).

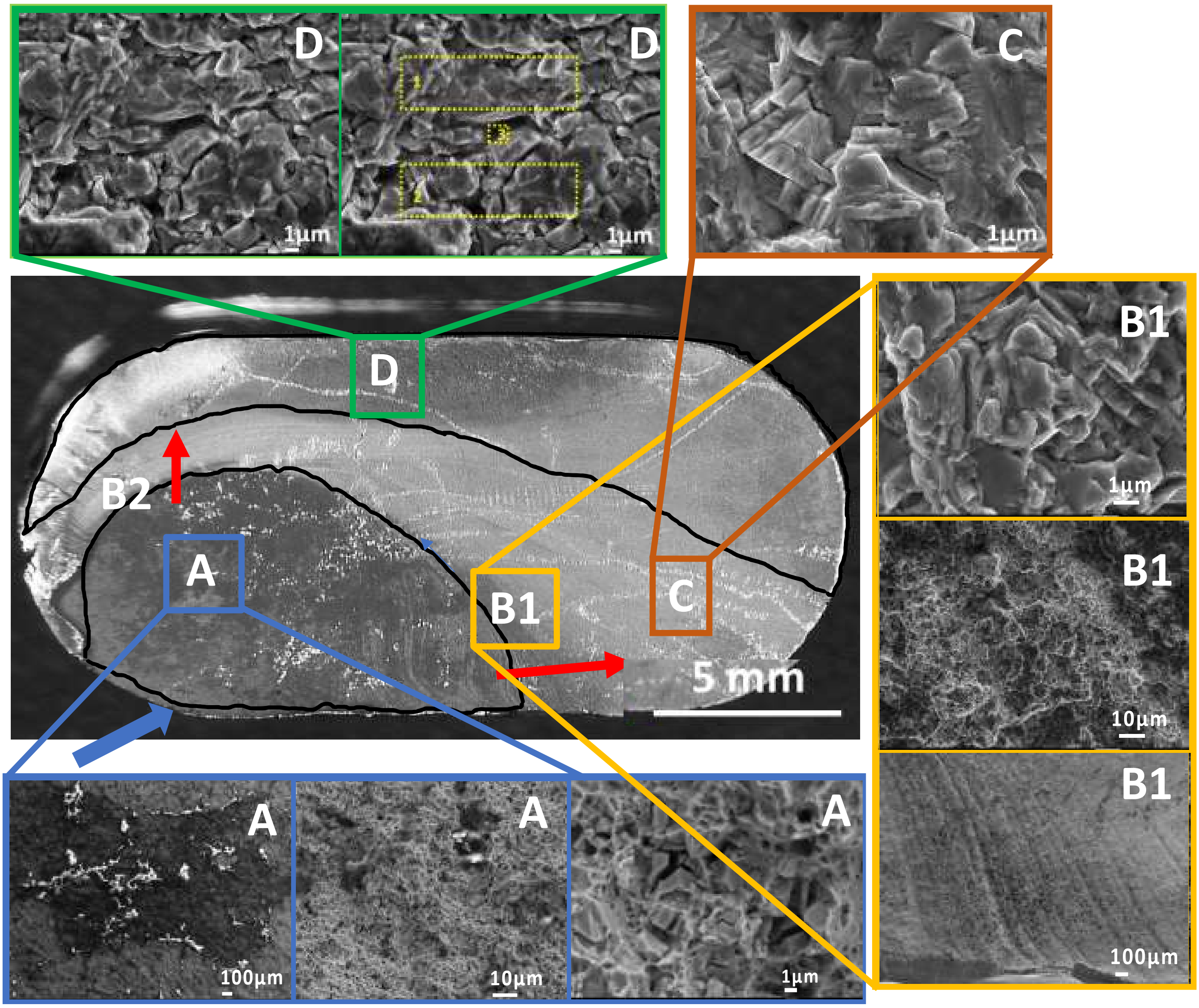

Figure 1: SLM of the fractured surface of CoCrMo neck on the main inside image represents the mechanism of CoCrMo alloy modular neck fracture. The blue arrow indicates the crack initiation; Zone-A the corroded fractured surface with deposited biological material is shown in three SE images in three blue marked panels: the left panel A at lower magnification, the detail of fatigue fracture and cracked carbides at higher magnification, panel A in the middle, and cracked carbide at highest magnification in the right panel A. The red arrows show the direction of fatigue crack propagation in the location B1 and location B2. The fatigue striations were observed in SE images in areas marked in yellow, the microstructures details are shown in middle and upper panels. At Zone C, the fracture surface is very rough and angular. The fracture surface shows several secondary cracks that are perfectly straight and short. Next to these flat cracks, larger secondary cracks can be seen, which are branched and longer than the flat ones. The lower SEI shows the crack propagation, and the middle and upper SEI shows the details at higher magnifications. The SE image of Zone-D marked green, shows a sudden fracture. Zone-D in the right panel shows areas of EDS analysis of the fracture surface (yellow squares marked in the right panel). From (Dolinar et al., 2023).

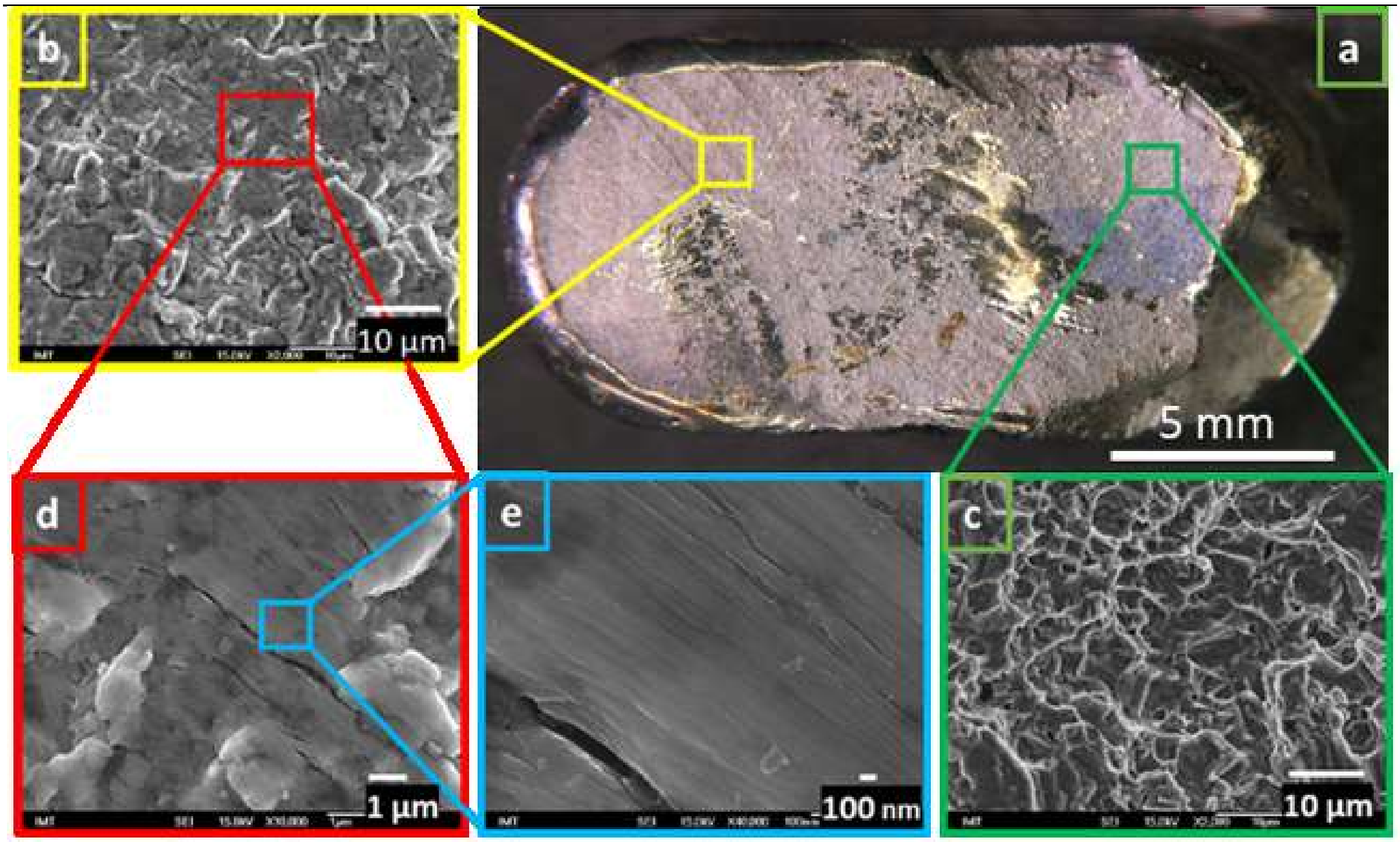

Figure 2. (**a**) Image of different fractured surface regions of fractured Ti6Al4V modular neck; (**a–b**) yellow-marked region and yellow-framed SE image of fatigue failure and with higher magnifications (**b,d,e**); (**a,c**) green-marked region and green-framed SE image with sudden ductile fracture. Organic deposits on fractured Ti6Al4V surface due to PE nanoparticle migration were found and visible as blue color (**a**). From (Dolinar et al., 2023).

3. Conclusions

The fretting, corrosion, and fatigue occurred on both neck–stem retrievals of the same (Ti6Al4V neck/Ti6Al4V stem) and different (CoCrMo neck/Ti6Al4V stem) metal systems. The cracked femoral neck made of CoCrMo alloy was dynamically loaded, exposed to a corrosive medium, and surrounded by a Ti6Al4V alloy with a different electrochemical potential. Due to the constant dynamic load and a combination of different materials in a corrosive medium, galvanic corrosion on the surface of the modular neck occurred. The different-metal system made of CoCrMo/Ti6Al4V suffered more corrosion than the same-metal system made of Ti6Al4V/Ti6Al4V alloy due to additional galvanic corrosion. The nature of the in vivo mechanisms causing the formation of the bio-tribo-corrosion processes needs to be understood and characterized so that appropriate changes in design and materials can be implemented.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Azar FM, Canale ST, Beaty JH, Arthroplasty of the hip. In *Campbell's Operative Orthopaedics*, 13th ed.; Elsevier: Amsterdam, The Netherlands, 2016; pp. 166–337.
2. Baleani M, Toni A, Ancarani C, Stea S, Bordini B. Long-term survivorship of an exchangeable-neck hip prosthesis with a Ti-alloy/Ti-alloy neck-stem junction. Arch Orthop Trauma Surg. 2023; 143:3649-3657. DOI:10.1007/s00402-022-04634-8
3. Castagnini F, Bordini B, Lucchini S, Cosentino M, Tassinari E, Traina F. Mid-term outcomes of revision hip arthroplasty due to titanium modular neck failure. Arch Orthop Trauma Surg. 2023;143:5909-5918. DOI:10.1007/s00402-023-04805-1

4. Dolinar D, Gorenšek M, Jenko M, Godec M, Šetina Batič B, Donik Č, Kocijan A, Debeljak M, Kocjančič B. Biomaterials in endoprosthetics. Mater. Tehnol. 2018, 52: 89–98. https://doi.org/10.17222/mit.2017.196.
5. Dolinar D, Gorenšek M, Avsec K, Šetina Batič B, Hočevar M, Godec M, Žužek B, Debeljak M, Jenko M, Grant JT, et al. Mechanisms of Premature Fracture in Modular Neck Stems Made of CoCrMo/Ti6Al4V and Ti6Al4V/Ti6Al4V Alloy. Coatings. 2023; 13:1255. https://doi.org/10.3390/coatings13071255
6. Ellman MB, Levine BR. Fracture of the Modular Femoral Neck Component in Total Hip Arthroplasty. J Arthroplasty. 2013; 28:196.e1-196.e5. DOI: 10.1016/j.arth.2011.05.024.
7. Fokter SK, Levašič V, Kovač S. The innovation trap: Modular neck in total hip arthroplasty. Zdrav. Vestn. 2017, 86, 1–12. On line edition.
8. Gilbert JL, Buckley CA, Jacobs JJ. In vivo corrosion of modular hip prosthesis components in mixed and similar metal combinations. The effect of crevice, stress, motion, and alloy coupling. J Biomed Mater Res. 1993; 27:1533-1544. DOI:10.1002/jbm.820271210
9. Goffton WT, Illical EM, Feibel RJ, Kim PR, Baulle PEA. Single-Center Experience With a Titanium Modular Neck Total hip Arthroplasty. J. Arthroplast. 2017, 32: 2450–2456. http://doi.org/10.1016/j.arth.2017.03.025.
10. Gorenšek M, Jenko M. Expert Opinion about the Relevant Proceedings of the District Court in Celje: Fracture of a Modular Prosthesis with a Mobile Neck, Manufactured by Wright Medical Technology/MICROPORT; Profemur Z/Profemur Plus: Ljubljana, Slovenia, 2018; pp. 1–45.
11. Jenko M, Gorensek M, Godec M, Hodnik M, Setina Batic B, Dolinar D. Surface chemistry and microstructure of metallic biomaterials for hip and knee endoprosthesis. Appl. Surf. Sci. 2018, 427: 584–593. https://doi.org/10.1016/j.apsusc.2017.08.007.
12. Maniscalco P, Quattrini F, Ciatti C, et al. Neck modularity in total hip arthroplasty: a retrospective study of nine hundred twenty-eight titanium neck implants with a maximum follow-up of eighteen years. Int Orthop. 2020; 44:2261-2266. DOI:10.1007/s00264-020-04686-8
13. McTighe T, Brazil D, Keppler L, Keggi J, McPherson E. Metallic Modular Taper Junctions in Total Hip Arthroplasty. Reconstr. Rev. 2015; 5. https://doi.org/10.15438/rr.5.2.108.
14. Oladokun A, Pettersson B, Bryant M, Engqvist H, Persson B, Hall R, Neville, A. The Fretting of CoCrMo and Ti6Al4V Alloys in Modular Prostheses. Tribol.-Mater. Surf. Interfaces 2015, 9:165–173. https://doi.org/10.1179/1751584X15Y.0000000014.
15. Park CV, Lim SJ, Park YS. Modular Stems: Advantages and Current Role in Primary Total Hip Arthroplasty. *Hip Pelvis* **2018**, *30*, 147–155. http://doi.org/10.5371/hp.2018.30.3.147.
16. Solarino G, Vicenti G, Carrozzo M, Ottaviani G, Moretti B, Zagra L. Modular neck stems in total hip arthroplasty: current concepts. EFORT Open Rev. 2021; 6:751-758. DOI:10.1302/2058-5241.6.200064
17. Soteranos NG, Sauber TJ, Todd TT, Tupis T. Modular Femoral Neck Fracture after primary total hip arthroplasty. *J. Arthroplast.* 2013; 28:196–199. https://doi.org/10.1016/j.arth.2012.03.050
18. Viceconti M, Baleani M, Squarzoni S, Toni A. Fretting wear in a modular neck hip prosthesis. J Biomed Mater Res. 1997; 35:207-216. DOI:10.1002/(sici)1097-4636(199705)35:2<207::aid-jbm9>3.0.co;2-r
19. Wright G, Sporer S, Urban R, Jacobs J. Fracture of a modular femoral neck after total hip arthroplasty: a case report. J Bone Joint Surg Am. 2010; 92:1518-1521. DOI:10.2106/JBJS.I.01033