

## Trunnionosis in Total Knee Arthroplasty: Is it a clinical problem?

Ricardo Pulido, Benjamin Kester, Ran Schwarzkopf

Ricardo Pulido, Benjamin Kester, Ran Schwarzkopf, Division of Adult Reconstruction, NYU Langone Health Orthopedic Hospital, Hospital for Joint Diseases, 301 East 17th Street, New York, NY 10003, the United States

**Conflict-of-interest statement:** The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

**Open-Access:** This article is an open-access article which was selected by an in-house editor and fully peer-reviewed by external reviewers. It is distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>

**Correspondence to:** Ran Schwarzkopf, M.D., Associate Professor, Adult Reconstructive Division, Director of the NYU Knee Center, Department of Orthopedic Surgery, NYU Langone Health Orthopedic Hospital, Hospital for Joint Diseases, 301 East 17th Street, New York, NY 10003, the United States.

**Email:** Gunasekaran Kumar

**Telephone:** +1-212-598-6000

**Received:** October 13, 2017

**Revised:** December 19, 2017

**Accepted:** December 22 2017

**Published online:** December 28, 2017

### ABSTRACT

Modularity of prosthetic implants is increasingly being utilized for the optimization and personalization of components in total hip and knee arthroplasty. However, due to the increasing number of modular implants being utilized, an adverse event termed trunnionosis has gained prevalence. Trunnionosis is defined as corrosion and wear of the taper junction in modular prostheses. It is postulated that this corrosive wear generates metal debris, which leads to component failure and requires revision of the prosthetic implant. The process of trunnionosis has been extensively studied in total hip arthroplasty.

However, few studies have examined the process of trunnionosis in total knee arthroplasty. The aim of this review is to examine the literature regarding trunnionosis following total knee arthroplasty. Specifically, we aim to determine if trunnionosis following total knee arthroplasty is a rare clinical problem, or one that deserves greater attention.

**Key words:** Trunnionosis; TKA; Total Knee Arthroplasty; Metallosis; Modular implants

© 2017 The Author(s). Published by ACT Publishing Group Ltd. All rights reserved.

Pulido R, Kester B, Schwarzkopf R. Trunnionosis in Total Knee Arthroplasty: Is it a clinical problem? *International Journal of Orthopaedics* 2017; 4(6): 837-840 Available from: URL: <http://www.ghrnet.org/index.php/ijo/article/view/2164>

### INTRODUCTION

Component modularity is increasingly being used in total hip arthroplasty (THA) as it allows for patient-directed customization of the prosthetic implant<sup>[1]</sup>. Compared to the original monobloc hip models, customization allows the surgeon to intraoperatively adjust head size, neck length, and anteversion with ease<sup>[1,2]</sup>. Specifically, the switch from the monobloc design to a modular one allows the surgeon to have better intraoperative control over proper hip offset and leg length<sup>[1,2]</sup>. Following its success in THA, component modularity was then utilized in total knee arthroplasty (TKA)<sup>[3]</sup>. However, modular designs in TKA have always been used to a lesser extent than in THA<sup>[4,5]</sup>. It is possible that the benefits of modularity for TKA are not as great as those for THA<sup>[4-6]</sup>. This is supported with prospective level I studies showing similar clinical outcomes when modular TKA is compared to non-modular TKA<sup>[7]</sup>. Thus the decision to use the modular design or not in TKA remains at the discretion of the surgeon and their available resources<sup>[7]</sup>.

The benefit of intraoperative versatility that modularity offers the surgeon is offset by its inherent creation of another source of metal debris<sup>[2,6]</sup>. The process of which has been given the term trunnionosis. Trunnionosis is typically defined as the corrosion at the Morse taper between the femoral head and stem<sup>[1,6]</sup>. A similar Morse taper exists

in the modular designs of some TKA components<sup>[8]</sup>. This additional junction, which was not present in the original monobloc model, is a potential source of metal debris<sup>[1,6,9,10]</sup>. Metal debris generated at this junction is thought to be due to fretting corrosion at the metal on metal interface<sup>[10]</sup>. Corrosion and subsequent micro motion at the trunnion deposits metal debris within local soft tissues<sup>[2,8]</sup>. This process has been shown to cause an adverse reaction to metal debris (ARMD) and is associated with increased prosthetic failures<sup>[9,11-13]</sup>.

ARMD has been studied extensively on metal-on-metal (MoM) bearings in THA. Many studies have shown MoM bearings to have increased rates of wear and metal debris production<sup>[6,10,14,15]</sup>. Initially this was attributed to the corrosion and wear of the MoM femoral acetabular interface<sup>[14]</sup>. This idea was based on the observation that the femoral acetabular interface is the site of the metal debris, which was seen in prior studies of metallosis<sup>[9]</sup>. However, both ARMD and extensive metal debris deposits have been seen with metal-on-polyethylene (MoP) prostheses as well<sup>[6,14,15]</sup>. This observation led to the conclusion that trunnionosis may be responsible for both MoM and MoP prosthetic failures and consequent revisions. More recently, it has been postulated that the metal debris generated at the trunnion may be different than the metal debris generated at the femoral acetabular interface<sup>[6]</sup>. Studies have even suggested that metal debris generated in trunnionosis is more biologically active and destructive to the soft tissues<sup>[6,12]</sup>. Although the mechanism remains unclear, this observation supports trunnionosis as a major cause of prosthetic failures<sup>[12]</sup>.

Most of the literature regarding implant trunnionosis stems from its effects in THA. Very few studies have examined trunnionosis in TKA<sup>[4]</sup>. In this review we attempt to examine and compile the known information regarding trunnionosis in TKA. Specifically, the authors want to present the similarities and differences of trunnionosis in THA and TKA, and determine if trunnionosis in TKA is a clinical problem that warrants further attention or research.

## METHODS

A literature search was performed using PubMed and Google Scholar. The following terms were used in various combinations: ‘trunnionosis’, ‘taper corrosion’, ‘ARMD’, ‘adverse reaction to metal debris’, ‘total knee arthroplasty’, and ‘TKA’. This search yielded 54 abstracts and book chapters describing trunnionosis after total joint replacement. Of these 54 abstracts, the authors identified 30 articles and book chapters which were relevant for further evaluation. This selection was based on prior reviews of trunnionosis, unique case series, and any article describing trunnionosis in the knee. There was no date limitation in the search.

Out of the 30 sources, 11 of them described the pathology and clinical implications of trunnionosis in TKA. These sources included background information pertaining to the similarities and differences seen in trunnionosis regarding TKA and THA. These sources also provided a few notable case reports of trunnionosis in TKA.

## DISCUSSION

### The Biomechanics and Bioelectrochemical Process of Trunnionosis

The taper junction in any modular design is subjected to shear forces and micromotion<sup>[16,17]</sup>. This motion damages two sides of the taper, resulting in fretting of the two interfaces and potentially corrosion if the process continues<sup>[16]</sup>. Corrosion of the taper junction may compound the damage already done by the biomechanical factor of fretting<sup>[17]</sup>. The creation of corrosion products have been shown to

be more destructive to the surrounding tissues and remaining metal, thus potentiating the damage<sup>[16,18]</sup>. This current understanding of the process of trunnionosis is still limited by its relative rarity as a complication in total joint replacement. However, this growing body of evidence suggests that the complex interaction between fretting and corrosion both play a role in the process of trunnionosis<sup>[16,19]</sup>.

Most of what we currently understand about the process of trunnionosis comes from retrospective studies in THA<sup>[16,17]</sup>. To the knowledge of the authors, the biomechanics and bioelectrochemical process of trunnionosis in TKA samples has yet to be studied. However, a further look into the literature suggests that trunnionosis in TKA and THA may be similar, as select studies have suggested similar variables are at play in both forms of trunnionosis<sup>[16-21]</sup>. These variables are: design and flexural rigidity of the trunnion, time in vivo, and material of the trunnion<sup>[16]</sup>. The individual risk of each variable and their pathogenesis contributing to trunnionosis is beyond the scope of this review, but these same variables are important considerations for both THA and TKA<sup>[16,20]</sup>.

### Similarities of Trunnionosis between TKA and THA

It has been suggested that modular prosthetic implants in both THA and TKA undergo trunnionosis in a similar fashion<sup>[20]</sup>. In both THA and TKA, the metallic alloys that are used and the metallic debris that is generated in trunnionosis are very similar<sup>[20]</sup>. The metal debris generated in trunnionosis has been studied in prosthetic implants containing chromium, cobalt, or nickel alloys as these metals have been reported to cause adverse effects in the surrounding soft tissues<sup>[4]</sup>. To our knowledge, the adverse effects of trunnionosis have been localized to the affected joint, characteristically causing pain, joint instability, pseudotumors, or stiffness<sup>[4,21,22]</sup>. Although metal ion levels can be elevated in the blood as these processes occur, there have been no reported instances of systemic complications due to trunnionosis arising from either THA or TKA<sup>[16,20]</sup>. However, it is theoretically possible for systemic complications to arise from trunnionosis based on studies seen in metallosis alone<sup>[16]</sup>. The treatment for trunnionosis in TKA is similar to that of THA<sup>[18]</sup>. The prosthetic removal, the soft tissue debridement for those regions affected by ARMD, and the subsequent revision is the mainstay of treatment<sup>[4,23,24]</sup>.

Monitoring and detecting trunnionosis in patients with either TKA or THA is performed in a similar fashion. The surgeon establishes the clinical diagnosis of trunnionosis based on history, physical exam, imaging, and serum metal ion levels<sup>[4,16]</sup>. No single test is diagnostic for trunnionosis, thus the surgeon risks the possibility of overdiagnosing this relatively rare complication for more common clinical complications<sup>[16]</sup>. This overdiagnosis becomes a concern in the asymptomatic patient with elevated levels of metal ions in the blood<sup>[12]</sup>. Currently there is debate on whether or not to systematically monitor blood levels for elevated metal ions<sup>[12,23]</sup>. The long-term benefit of this monitoring has yet to be established, but it may be a useful method to initiate closer follow up in both THA and TKA patients<sup>[12]</sup>.

### Why trunnionosis is studied less in TKA vs THA

Trunnionosis in TKA has been studied less than that of THA due to the prevalence of which trunnionosis occurs in each respective group<sup>[4,20]</sup>. This is likely due to the larger role of modular designs in THA vs TKA<sup>[25,27]</sup>. Whereas modularity is instrumental in both primary and revision THA cases, modularity in TKA is often only used for revision cases<sup>[4,26,27]</sup>. This discrepancy in primary cases is partly due to the concern that modular TKA prostheses reduce

bone density at the tibial metaphysis<sup>[7,27]</sup>. Perhaps another reason why trunnionosis has been neglected in TKA is due to the relative complexity of TKA failure compared to THA failure<sup>[28,29]</sup>. Whereas THA failure is often attributed to metal debris, polyethylene wear is more commonly cited as the cause for revisions in TKA<sup>[20,29]</sup>. Additionally, allergic reactions to metal have been reported more frequently in TKA than THA<sup>[29,30]</sup>. The propensity for revision TKA shortly after implantation, due to allergic reactions, may have masked a significant number of cases of trunnionosis following TKA<sup>[29]</sup>.

In short, the study of metal wear in TKA has largely been neglected<sup>[29]</sup>. There are simply many more examples of THA trunnionosis to observe and collect data on. However, while this may be true there is at least some evidence that the prevalence of trunnionosis in TKA may be larger than currently reported<sup>[23-28]</sup>. The underreporting of trunnionosis in TKA only amplifies the growing disparity in the literature regarding trunnionosis in TKA vs THA.

### Case Reports of Trunnionosis in TKA

In a retrospective study, Arnholt CM, *et al* collected 52 cobalt chromium femoral condyles following failed TKA to be examined for the causes of failure. Index operations were performed at least fifteen years prior to the analysis and the average patient age was 57 years. Their hypothesis was that prostheses that were in vivo long-term would most likely show evidence of degradation or metal debris<sup>[20]</sup>. The indications for total knee revisions were due to either loosening, instability, pain, or polyethylene wear<sup>[20]</sup>. The study found that 12% of the patients had evidence of ARMD and around 50% of the examined modular implants showed corrosive damage at the Morse Taper. Further investigation into the corrosive damage pattern suggested that metal debris was the product of fretting and corrosion, similar to what is seen in THA. Similarly, the discoloration observed in the tapers was indicative of corrosive damage commonly seen in trunnionosis with THA. These results are concerning enough to suggest the potential long-term risk of trunnionosis in TKA. However this study does have its limitations. For instance the initial indications for TKA were not recorded in this study. Comorbidities such as rheumatoid arthritis could have confounded the results. Additionally, the study was limited to long-term TKA revisions, thus the study is not generalizable to the short-term risk of trunnionosis in TKA. Although these limitations exist, the results attained from this study does warrant further investigation into the actual prevalence of trunnionosis in TKA.

A case report by McMaster and Patel<sup>[21]</sup> describes the unique case of a 65-year-old man following modular TKA for primary osteoarthritis. Within 20 months of the operation, he began experiencing pain, swelling, and loss of function to the implanted knee joint. Additionally, the patient's labs were found to be within normal limits except for elevated cobalt ion levels. However, the most recent post-operative radiographs demonstrated no evidence of osteolysis, radiolucent lines, or a change in component orientation<sup>[21]</sup>. Due to the deterioration in the patient's quality of life, surgical exploration was performed. Upon surgical exploration, black metal debris and fibrotic synovial tissue representative of ARMD was seen. The source was found to originate from the femoral component of the Morse Taper, signifying the process of trunnionosis as the cause for the eventual revision. Upon further evaluation, the taper showed apparent corrosive and fretting damage, similar to what is seen in trunnionosis for THA<sup>[21]</sup>. These intraoperative findings support the growing evidence that trunnionosis in TKA and THA may be more alike than they are different. Additionally, the clinical presentation and lab findings in this patient are very similar to the numerous case

reports of trunnionosis in THA. Although it is hard to make any conclusions from these limited case reports, the literature regarding trunnionosis in TKA continues to grow.

### Limitations

Literature regarding trunnionosis following TKA is sparse. During our literature search and review process, missing other examples of trunnionosis in TKA is a possibility. This may be due to our selection of word choices or combinations of words during the literature search. The sources that were extracted from our search are primarily limited to a few case reports and small case series. In contrast, there is over three decades of case reports, reviews, and basic science research regarding trunnionosis in THA<sup>[2,4]</sup>. The few sources regarding trunnionosis in TKA found on our search is a notable reflection of this discrepancy. Although corrosion in modular TKA has long been appreciated, only recently have we begun to consider trunnionosis as a cause for TKA failure<sup>[4]</sup>. No doubt modular components are more widely used in THA compared to TKA, and the pool of available cases is much larger. With time we expect the number of case reports for trunnionosis in TKA will increase and our understanding of this parallel process will increase as well.

Another limitation is the few strong inferences that can be made from the data collected, due to the limited sample size in our review. It is unclear following this review whether trunnionosis is a true clinical problem or a rare complication following TKA. The few sources on the subject suggest the latter, but our analysis of TKA revision cases suggests that a large number of cases are missed. One would think trunnionosis in THA, which is already an established clinical problem, would support trunnionosis in TKA also being a clinical problem. However, the minimal number of case reports cannot substantiate this claim, thus no inference can be made at this time. Yet, the results from our review should at least increase the awareness of this notable complication following revision TKA.

## CONCLUSIONS

There are limited case reports and studies regarding trunnionosis in TKA, thus making it difficult to assess the true clinical significance. However, the increasing utilization of modularity in TKA will surely provide valuable information, improving our understanding of this clinical problem. Additional research should be conducted in order to expand the current literature base and increase the awareness of trunnionosis to all modular designed prosthetics.

## REFERENCES

1. Mistry JB, Chughtai M, Elmallah RK, Diedrich A., Le S, Thomas M, Mont MA. Trunnionosis in total hip arthroplasty: a review. *Journal of Orthopaedics and Traumatology : Official Journal of the Italian Society of Orthopaedics and Traumatology*. 2016; **17(1)**: 1-6. [PMID: 26868420]; [DOI: 10.1007/s10195-016-0391-1]
2. Porter DA, Urban RM, Jacobs JJ, Gilbert JL, Rodriguez JA, Cooper HJ. Modern Trunnions Are More Flexible: A Mechanical Analysis of THA Taper Designs. *Clinical Orthopaedics and Related Research*. 2014; **472(12)**: 3963-3970. [PMID: 25267272]; [DOI: 10.1007/s11999-014-3965-3]
3. Laskin RS. The Classic: Modular Total Knee-Replacement Arthroplasty. A Review of Eighty-nine Patients. *Clinical Orthopaedics and Related Research*. 2008; **466(11)**: 2581-2588. [PMID: 18795387]; [DOI: 10.1007/s11999-008-0461-7]
4. Arnholt C, MacDonald DW, Tohfafarosh M, Gilbert JL, Rinnac CM, Kurtz SM, Implant Research Center Writing Committee, Klein G, Mont MA, Parvizi J, Cates HE, Lee GC, Malkani A,

- Kraay M. Mechanically Assisted Taper Corrosion in Modular TKA. *The Journal of arthroplasty*. 2014; **29**(90): 205-208. [PMID: 24996586]; [DOI: 10.1016/j.arth.2013.12.034]
5. Barrack, RL. Modularity of Prosthetic Implants. *Journal of the American Academy of Orthopaedic Surgeons*. 1994; **2**(1): 16-25 [PMID: 10708990]
  6. Pastides PS, Dodd M, Sarraf KM, Willis-Owen CA. Trunnionosis: A pain in the neck. *World Journal of Orthopedics*. 2013; **4**(4): 161-166. [PMID: 24147250]; [DOI: 10.5312/wjo.v4.i4.161]
  7. Makhdom AM, Parvizi J. Modular versus nonmodular tibial inserts in total knee arthroplasty: what are the differences? *Ann Transl Med* 2017; **5**(10): 225 [PMID: 28603740]; [DOI: 10.21037/atm.2017.02.25]
  8. Durig N, Pace T, Broome B, Osuji O, Harman MK. Clinical Outcomes of Tibial Components with Modular Stems Used in Primary TKA. *Advances in Orthopedics*. Vol.2014, Article ID 651279 [PMID: 24669319]; [DOI: 10.1155/2014/651279]
  9. Kirkham JR, Petscavage JM, Richardson ML. Metallosis: CT findings in a total hip arthroplasty. *Radiology Case Reports*. 2010; **5**(2): 410. [PMID: 27307862]; [DOI: 10.2484/rcr.v5i2.410]
  10. Drummond J, Tran P, Fary C. Metal-on-Metal Hip Arthroplasty: A Review of Adverse Reactions and Patient Management. Mootanah R, ed. *Journal of Functional Biomaterials*. 2015; **6**(3): 486-499. [DOI: 10.3390/jfb6030486]
  11. Rajpura A, Board TN. The evolution of the trunnion. *Hip International*. 2015; **25**(1): 2-6 [PMID: 25633761]; [DOI: 10.5301/hipint.5000213]
  12. Langton DJ, Sidaginamale RP, Joyce TJ, Natu S, Blain P, Jefferson RD, Rushton S, Nargol AV. The clinical implications of elevated blood metal ion concentrations in asymptomatic patients with MoM hip resurfacings: a cohort study. *BMJ Open*. 2013; **3**(3): e001541 [PMID: 23482990]; [DOI: 10.1136/bmjopen-2012-001541]
  13. Matsen LK, Chen AF, Deirmengian GK, Hozack WJ, Sharkey PF. Catastrophic Femoral Head-Stem Trunnion Dissociation Secondary to Corrosion. *The Journal of Bone and Joint Surgery*. 2016; **98**(16): 1400-1404 [PMID: 27535443]; [DOI: 10.2106/JBJS.15.00914]
  14. Balso CD, Teeter MG, Tan SC, Howard JL, Lanting BA. Trunnionosis: Does Head Size Affect Fretting and Corrosion in Total Hip Arthroplasty? *The Journal of Arthroplasty*. 2016; **31**(10): 2332-2336 [PMID: 27067470]; [DOI: 10.1016/j.arth.2016.03.009]
  15. Hothi HS, Eskelinen AP, Berber R, Lainiala OS, Moilanen TP, Skinner JA, Hart AJ. Factors Associated with Trunnionosis in the Metal-on-Metal Pinnacle Hip. *The Journal of Arthroplasty*. 2017; **32**(1): 286-290 [PMID: 27471212]; [DOI: 10.1016/j.arth.2016.06.038]
  16. Lanting B, Naudie D, McCalden RW. Clinical Impact of Trunnion Wear after Total Hip Arthroplasty. *The Journal of Bone and Joint Surgery*. 2016; **4**(8) [PMID: 27603271]; [DOI: 10.2106/JBJS.RVW.15.00096]
  17. Wassef AJ, Schmalzried TP. Femoral taperosis: an accident waiting to happen? *Bone Joint J*. 2013; **95-B**(11)(Suppl A): 3-6. [PMID: 24187342]; [DOI: 10.1302/0301-620X.95B11.32630]
  18. Rogers GT. In vivo production of hexavalent chromium. *Biomaterials*. 1984; **5**(4): 244-5. [DOI: 10.1016/0142-9612(84)90024-3]
  19. Elkins JM, Callaghan JJ, Brown TD. Stability and Trunnion Wear Potential in Large-diameter Metal-on-Metal Total Hips: A Finite Element Analysis. *Clinical Orthopaedics and Related Research*. 2014; **472**(2): 529-542. [PMID: 24218160]; [DOI: 10.1007/s11999-013-3244-8]
  20. Arnholt CM, MacDonald DW, Malkani AL, Klein GR, Rinnac CM, Kurtz SM, Implant Research Center Writing Committee, Kocgoz SB, Gilbert JL. Corrosion Damage and Wear Mechanisms in Long-Term Retrieved CoCr Femoral Components for Total Knee Arthroplasty. *The Journal of Arthroplasty*. 2016; **31**(12): 2900-2906 [PMID: 27426028]; [DOI: 10.1016/j.arth.2016.05.006]
  21. McMaster WC, Patel J. Adverse Local Tissue Response Lesion of the Knee Associated with Morse Taper Corrosion. *The Journal of Arthroplasty*. 2013; **28**(2): 375-378. [PMID: 22704030]; [DOI: 10.1016/j.arth.2012.04.005]
  22. Hirschmann M, Becker R. (2015). The Unhappy Total Knee Replacement: A comprehensive Review and Management Guide. *Springer International Publishing* [DOI: 10.1007/978-3-319-08099-4]
  23. Engh CA, Ho H, Padgett DE. The Surgical Options and Clinical Evidence for Treatment of Wear or Corrosion Occurring With THA or TKA. *Clinical Orthopaedics and Related Research*. 2014; **472**(12): 3674-3686. [PMID: 25024023]; [DOI: 10.1007/s11999-014-3652-4]
  24. Bonutti P, Pivec R, Issa K, Kapadia BH, Banerjee S, Harwin SF, Mont MA, Bauer TW. Delamination of Tantalum Porous Coating From a TKA Due to Regional Dissemination of Debris. *ORTHOPEDICS*. 2013; **36**: 600-604. [PMID: 23937736]; [DOI: 10.3928/01477447-20130724-03]
  25. Eckert JA, Mueller U, Jaeger S, Panzram B, Kretzer JP. Fretting and Corrosion in Modular Shoulder Arthroplasty: A Retrieval Analysis. *BioMed Research International*. 2016; **2016**: 1695906. [PMID: 27433471]; [DOI: 10.1155/2016/1695906]
  26. Rand JA. Modular Augments in Revision Total Knee Arthroplasty. *Orthopedic Clinics of North America*. 1998; **29**(2): 347-353 [PMID: 9553580]; [DOI: 10.1016/S0030-5898(05)70333-3]
  27. Lonner JH, Klotz M, Levitz C, Lotke PA. Changes in bone density after cemented total knee arthroplasty: influence of stem design. *Journal of Arthroplasty*. 2001; **16** (1): 107-111 [PMID: 11172279]; [DOI: 10.1054/arth.2001.16486]
  28. Mokris JG, Smith SW, Anderson SE. Primary total knee arthroplasty using the Genesis total knee arthroplasty system: 3- to 6-year follow-up study of 105 knees. *Journal of Arthroplasty*. 1997; **12**(1): 91-98 [PMID: 9021508]; [DOI:10.1016/S0883-5403(97)90053-X]
  29. Kretzer JP, Reinders J, Sonntag R, Hagmann S, Streit M, Jaeger S, Moradi B. Wear in total knee arthroplasty—just a question of polyethylene?: Metal ion release in total knee arthroplasty. *International Orthopaedics*. 2014; **38**(2): 335-340. [PMID: 24218115]; [DOI: 10.1007/s00264-013-2162-4]
  30. Rau C, Thomas P, Thomsen M. Metal sensitivity in patients with joint replacement arthroplasties before and after surgery. *Orthopaede*. 2008; **37**: 102-110. [PMID: 18210091]; [DOI: 10.1007/s00132-007-1186-0]

Peer Reviewer: Gunasekaran Kumar