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Ceramic Coatings Confer No Survivorship Advantages in Total Knee Arthroplasty—A Single-Center Series of 1641 Knees

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ABSTRACT

Background: Ceramic coatings in total knee arthroplasty have been introduced with the aim of reducing wear and consequently improving implant survivorship. We studied both cobalt-chrome-molybdenum (CoCrMo) and ceramic-coated components of the same implant design from a single center to identify if the ceramic coating conferred any benefit.

Methods: We identified 1641 Columbus total knee arthroplasties (Aesculap AG, Tüttlingen, Germany) from a prospectively collected arthroplasty database. Of the 1641, 983 were traditional CoCrMo, and 659 had the Columbus AS ceramic coating. Patients were followed up until death or revision of any component of the implant.

Results: There was no significant difference in implant survivorship using any component revision as the endpoint between the CoCrMo femur and the ceramic-coated femur at a mean of 9.2 years in follow-up for the CoCrMo group and 5 years for the ceramic-coated group (37 vs 14; $P = .76$). There was no reduction in the proportion of components revised for aseptic loosening or infection in the ceramic-coated cohort.

Conclusions: At midterm follow-up, there was no benefit in terms of implant survivorship in using a ceramic coating.

Background

The demand for total knee arthroplasty (TKA) continues to rise worldwide. Within the United States, exponential growth has been predicted, suggesting 1.9 million TKAs per annum in 2030, an increase in annual TKA volume by 182% from 2014 to 2030 [1]. Projections within Australia anticipate an exponential increase in the annual incidence of TKA by 276% by 2030 [2].

With increasing demand for primary total knee replacement and with aseptic loosening and polyethylene wear representing some of the most common causes for a revision surgery, manufacturers have looked to improve biomaterial designs to optimize implant longevity [3].

This has led to the refinement of more traditional bearing surfaces such as cobalt-chrome-molybdenum (CoCrMo) TKAs and ultra-high-molecular-weight polyethylene with respect to their manufacturing, surface chemistry, and topography in improving tribological performance [4,5]. Alternative component bearing surfaces, most commonly in the form of implant coatings, have also been introduced. These have generally taken the form of a ceramic coating such as oxidized zirconium; Oxinium (Smith & Nephew, Memphis, TN) or zirconium nitride as in the case of the Columbus AS prosthesis (Aesculap AG, Tüttlingen, Germany).

The Columbus AS system was developed with a view to improving implant longevity. It uses a 7-layer coating encasing the implant to achieve a ceramic coating of zirconium nitride [6]. The purported benefits of this coating are increased material hardness

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and a significant reduction in wear in vitro in comparison to the more standardized CoCrMo prosthesis [7]. A theoretical secondary gain from the ceramic coating is that it provides additional benefits of reduction in metal ion release and increased resistance to material ablation [8].

We report on a case series from a single institution, evaluating whether the purported benefits of ceramic coating the bearing surface are identified in comparison to the more traditional CoCrMo articulation.

Material and methods

Using a prospectively maintained arthroplasty database which is curated by a dedicated audit clerk, we identified all patients receiving a Columbus TKA prosthesis with either a CoCrMo femur or a ceramic-coated (AS) femur, with a minimum follow-up period of 2 years. These operations were performed by or under the supervision of 1 of the senior authors (P.J.R.) who routinely used this implant as his primary TKA prosthesis. A medial parapatellar approach was used in all cases, and a cruciate-retaining, fixed-bearing prosthesis was implanted using a computer navigation software program (Orthopilot; B. Braun, Sheffield, UK). All components were cemented using Palacos R + G high-viscosity cement (Hereaus medical GmbH, Wehrheim, Germany). The patella was resurfaced in 623 of 659 (94.5%) AS and 547 of 982 (55.7%) CoCrMo TKAs. All patients received intravenous antibiotics and thromboprophylaxis as per local guidelines. Patients were mobilized full weight bearing on the day of surgery or the day after and discharged home once they were able to mobilize and climb stairs independently. Patients were routinely followed up in clinic at 6 weeks and 6 months, with x-ray performed at 6 months and then again at 7 years postoperatively and 3 yearly thereafter. Where patients had not returned to clinic, they were contacted by telephone to confirm their outcome.

Patient demographics are shown in Table 1.

The primary outcome was revision for any cause. Revisions were identified using our own database, a review of patient records and radiographs, and cross-checked with the National Joint Registry (NJR) to capture any revisions performed at other institutions.

Secondary analysis included the proportion revised for aseptic loosening and infection, as these are theoretical advantages of a ceramic-coated TKA. These secondary outcomes were chosen because aseptic loosening may be a result of polyethylene wear and osteolysis [9], and there is some emerging evidence in total hip arthroplasty that ceramic bearings may be protective against prosthetic joint infection [10].

Table 1
Patient demographics.

Patient demographics	CoCrMo TKA (n = 982)	Ceramic-coated TKA (n = 659)	*P* value
Age	70.8	68.3	<.0001[a]
Male	566 (57.63%)	272 (41.27%)	<.0001[b]
ASA grade			
ASA 1	111 (11.29%)	20 (%3.04)	<.0001[b]
ASA 2	659 (67.03%)	502 (76.17%)	<.0002[b]
ASA 3	211 (21.46%)	137 (20.79%)	.74[b]
ASA 4	1 (0.22%)	0	-
Diagnosis			
Osteoarthritis	969 (98.7%)	649 (98.48%)	.70[b]
Rheumatoid/inflammatory arthritis	11 (1.12%)	7 (1.06%)	.90[b]
Other	2 (0.18%)	3 (0.46%)	.30[b]
BMI (kg/m^2)	30.8	32.3	<.0001[a]

BMI, body mass index; ASA, American Society of Anaesthesiologists.
[a] t-test (2-tailed).
[b] Chi-square test.

Statistics

A survivorship analysis was performed using Graphpad Prism 8.3.0 (Graphpad Software, San Diego, CA). Annual implant survivorship was estimated using the Kaplan-Meier methodology. The survival analysis curves were compared using a Wilcoxon test.

Results

During the study period, 192 patients died (148 in the CrCoMo group and 44 in the ceramic-coated group). These patients were included up until the time of death, and their medical records were examined, or, if necessary, their general practitioner was contacted to ensure that their implant had not been revised. Where patients could not be contacted, they were included until their last follow-up contact and again their general practitioner was contacted, and the NJR was checked to ensure the implant had not been revised. The mean follow-up duration was 5 years (range 1.0-9.3) for the ceramic-coated group and 9.2 years (range 2.1-17.2) for the CoCrMo group.

Revision for any cause

Thirty-seven CoCrMo TKAs were revised (3.77%), at a mean of 5.3 years (range 0.1-12.7) postoperatively. Fourteen ceramic-coated TKAs were revised (2.12%), at a mean of 3.6 years (range 0.9-7.3) postoperatively. Figure 1 shows the Kaplan-Meier survivorship with revision as the endpoint. This difference was not statistically significant ($P = .76$). Indications for revision can be seen in Table 2. Table 3 shows the number at risk, numbrer revised and survivorship at each time point.

Kaplan-Meier implant survivorship curves are shown in Figure 1, with revision for any cause as the endpoint.

Discussion

We present a series of both metal and ceramic-coated implants of the same design, from a single center. At short-term to midterm follow-up, we have not identified significant benefits of the ceramic coating in terms of implant survivorship or reduction in the proportion of implants revised for wear or loosening (Fig. 2). There are of course limitations with this study, particularly the retrospective nature of the analysis, the lack of randomization, and the difference in the length of follow-up. We also accept that the lack of patient-reported outcome measures is a major limitation.

The theoretical advantages of ceramic coatings are their inert biochemical properties, reduced friction coefficient, and increased hardness. In vitro analysis using simulators has demonstrated improved TKA wear properties using ceramic-coated implants with

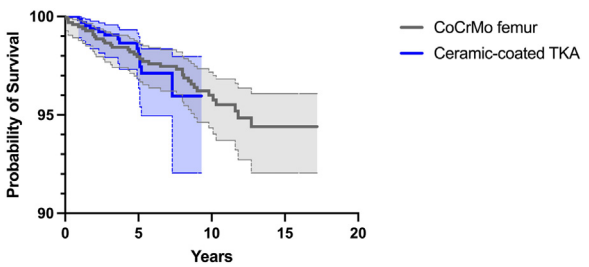

Figure 1. Kaplan-Meier implant survivorship analysis using revision as the endpoint ($P = .76$, Wilcoxon test).

Table 2
Indications for revision in each cohort.

Indication	CoCrMo TKA	AS TKA
Infection	14 (38%)	4 (29%)
Aseptic loosening	7 (20%)	6 (43%)
Instability	10 (27%)	3 (21%)
Malalignment	0	1 (7%)
Polyethylene wear	1 (2.5%)	0
Patellar resurfacing	2 (5%)	0
Stiffness	2 (5%)	0
Pain	1 (2.5%)	0
Total	37 (100%)	14 (100%)

polyethylene bearings [11–13]. However, conflicting survivorship data for such implants in comparison to their equivocal CoCrMo counterparts exist within the literature [14]. In vivo case-matched retrieval analysis of such ceramic bearing surfaces has demonstrated both reductions in ultra-high-molecular-weight polyethylene wear of the tibial inserts as well as reduced damage to femoral components themselves in direct comparison to their CoCrMo femoral counterparts [15]. While theoretically, and as demonstrated by implant retrieval, such coatings can reduce material wear, this has not yet been shown to have a clinical benefit in case comparisons. Vertullo et al. assessed 12-year survivorship of the Genesis II (Smith & Nephew, Memphis, TN) femoral components in both standard CoCrMo and Oxinium coating [14]. There was no identifiable reduction in revision rate of the Oxinium-coated Genesis II femoral component when compared to the CoCrMo Genesis II component for all-cause revision (loosening/lysis, infection) [14].

Registry data can also be used to examine survivorship of ceramic-coated and metal implants of the same design [3]. The 18th edition of the NJR demonstrates ceramic coatings are associated with significantly higher revision rates at 15 years of follow-up; 3.49% for the CoCrMo Genesis II vs 7.67% for the Oxinium Genesis II. There are significant differences in numbers between the CoCrMo and Oxinium cohorts; 85,534 vs 11,362, respectively. The median age and interquartile range (IQR) are also significantly different between the 2 cohorts, with the Oxinium Genesis II having a median age of 59 (IQR 54-65) vs 71 (IQR 65-77) for the CoCrMo Genesis II [3]. This age variation may account for the reduced survivorship of the Oxinium Genesis II as younger patients are known to have an increased revision rate following primary TKA [16].

There are few outcome studies of the Columbus AS TKA published, but the 18th NJR demonstrates little early survivorship benefit for the Columbus AS in comparison to the Columbus CoCrMo prosthesis [3]. While it should be noted that again there are significant variations in cohort size, 1260 vs 15,909 (AS vs CoCrMo), and age between the 2 cohorts, 65 (IQR 59 − 71.5) vs 70 (IQR 64 − 76), the IQRs overlap, so this is not statistically significant [3]. As the AS Columbus was released to the market after the CoCrMo component, the follow-up period became shorter within the NJR. A 5-year revision analysis demonstrates a slightly, but not statistically significantly, higher revision rate between the AS Columbus at 2.42% (95% confidence interval 1.46-3.98) and CoCrMo Columbus at 2.05% (95% confidence interval 1.82-2.32) [3]. The anticipated benefit of ceramic coatings is the long-term survivorship secondary to aseptic loosening, and therefore, variations in implant survivorship between the cohorts may not be appreciated until results are obtained with longer term follow-up.

We have identified similar differences between the cohorts in our own series. The cohort sizes were different, with 982 patients receiving a CoCrMo Columbus and 659 patients receiving an AS Columbus. The series predominantly represents a single surgeon's

Table 3
Implant survival, numbers at risk, and 95% confidence intervals at each time point for each cohort.

Years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CoCrMo femur															
Implant survival estimate	99.5%	99.0%	98.7%	98.4%	98.0%	97.6%	97.5%	97.0%	96.2%	96.0%	95.5%	94.8%	94.4%	94.4%	94.4%
95% Confidence interval	98.8%-99.7%	98.1%-99.4%	97.7%-99.2%	97.4%-99.1%	96.8%-98.4%	96.3%-98.4%	96.2%-98.3%	95.7%-98.0%	94.6%-97.4%	94.3%-97.2%	93.7%-96.8%	92.7%-96.4%	92.0%-96.1%	92.0%-96.1%	92.0%-96.1%
Number at risk	983	951	908	303	817	774	727	658	548	417	337	256	190	122	49
Cumulative number revised	5	10	13	15	19	22	23	24	30	32	34	36	37	37	37
Ceramic-coated femur															
Implant survival estimate	99.8%	99.4%	99.1%	98.7%	98.1%	97.1%	97.1%	96.0%	96.0%	N/A	N/A	N/A	N/A	N/A	N/A
95% Confidence interval	98.9%-99.97%	98.4%-99.8%	97.9%-99.6%	97.3%-99.3%	96.4%-99.0%	95.0%-98.4%	95.0%-98.4%	92.0%-98.4%	92.0%-98.0%	N/A	N/A	N/A	N/A	N/A	N/A
Number at risk	654	628	574	451	330	227	115	37	6	N/A	N/A	N/A	N/A	N/A	N/A
Cumulative number revised	1	4	6	8	10	13	13	14	14	N/A	N/A	N/A	N/A	N/A	N/A

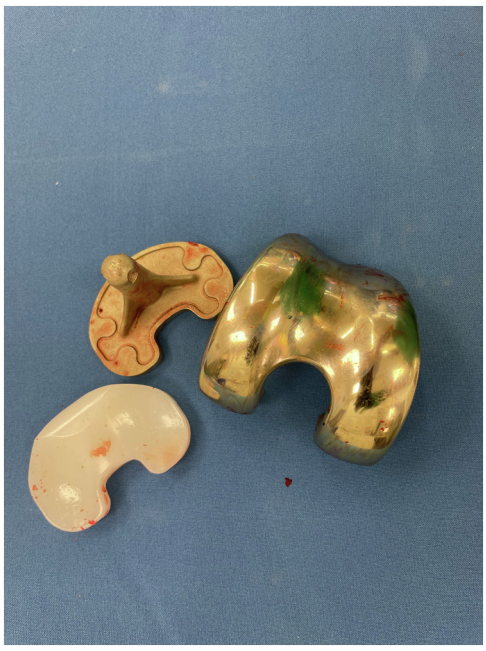

Figure 2. An explanted Columbus TKA with AS ceramic coating. This TKA was revised for aseptic loosening.

experience, who routinely used both the CoCrMo and AS Columbus; therefore, issues of implant familiarity and learning curve are not relevant. We also report differences in patients' age and body mass index between the 2 cohorts. This was due to the initial preferential use of the AS Columbus in the younger patient cohort, where increased implant cost (approximately £200 more per case) was offset against the expected increase in implant survivorship. Within our cohort, the mean age of the patients receiving CoCrMo Columbus was 70.8 vs 68.3 years for the AS Columbus. Over time, the use of the AS Columbus became more universal, so the mean age groups in our 2 cohorts are closer than those in the NJR. The primary diagnosis and proportion of American Society of Anaesthesiologists-III grade patients were similar between the groups. There was a higher body mass index in the AS group (32.3 vs 30.8); this difference was also statistically significant.

A secondary hypothetical benefit of the ceramic coating includes the potential to reduce periprosthetic joint infection (PJI). The theoretical advantage of ceramic is the reduction in asperity size of ceramic material surfaces in comparison to that of CoCr, making the formation of biofilm less likely as well as wear debris being more biotolerant. This is thought to reduce the immune response in comparison to metal articulations, thereby reducing periarticular inflammation and its associated increased vascularity, which may in turn reduce the probability of hematogenous spread from other sources of infection. There have been suggestions within the total hip arthroplasty literature that ceramic bearings, both ceramic-on-ceramic (CoC) and ceramic-on-polyethylene (CoP), showed demonstrable reduction in the incidence of PJI in comparison to more traditional metal-on-polyethylene articulations. This literature does include some potential patient selection biases. The Australian Registry analysis by Madanat et al. identified reported benefits of PJI reduction in patients younger than 70 years with a CoC articulation [10]. A more comprehensive review has been performed by Holleyman et al. assessing PJI risk by bearing surface within the NJR database [17]. This demonstrated risk reduction in both CoC and CoP bearing surfaces. As with all registry analyses, there is no evaluation of patient comorbidities, which will play a significant role in the risk of PJI [17]. Selection bias also impacts the interpretation of these data sets as typically CoC and CoP articulations are used more often in the younger, fitter patient where the cost-benefit assessment supports their use.

Studies assessing PJI with ceramic bearing surfaces in TKA have failed to demonstrate similar correlations. Grimberg et al. assessed 117,660 TKAs performed in the German arthroplasty registry, proportionally one of the largest consumers of ceramic-coated implants [18]. They analyzed outcomes up to a maximum of 3 years postoperatively and failed to identify any significant difference in PJI reduction of the ceramic TKA cohort in comparison to the CoCrMo cohort. The ceramic-coated group had a slightly higher incidence of revision for PJI within 3 years (1.2% compared to 1% for the CoCrMo cohort) [18]. There was also a higher all-cause revision rate for ceramic TKA, which was thought to be associated with nonroutine use and patient risk factors.

The third potential benefit of ceramic-coated TKA is in the avoidance of metal allergy. This is a controversial topic with mixed evidence regarding its significance and an unclear correlation between cutaneous allergic response and deep tissue reaction [19]. The NJR demonstrates that 11,030 revision TKAs were performed for unexplained pain and that potentially these could include revisions due to metal hypersensitivity [3]. Histologically, synovial-like interface membrane (SLIM), specifically SLIM-VI, suggests that adverse tissue reactions can occur as a result of implanted materials demonstrating histological features consistent with allergy and/or hypersensitivity [20]. However, within the group of patients demonstrating SLIM-VI histological changes, it is difficult to differentiate whether the formation of this membrane is due to a true immunological allergic process or whether it is secondary to the particulate toxicity produced by wear, as seen in metal-on-metal articulations. In a recent systematic review of the literature, Matar et al. concluded that while hypoallergenic implants are viable alternatives for patients with self-reported or confirmed metal hypersensitivity if declared preoperatively, concerns remained over their long-term outcomes with ceramic implants outperforming titanium nitride–coated implants [21]. However, a recent study using a revision implant with a metal-on-metal hinge articulation did not show any decrease in Co or Cr blood metal ion levels when a ceramic coating was applied [22].

While the use of coated and ceramic implants seems an appealing proposition within this patient cohort, they do not appear to infer survivorship benefits [3]. This is not only demonstrated by inferior NJR survivorship of ceramic-coated TKAs but also by published case series demonstrating variable results. These variations have been demonstrated in most coated and ceramic implants including titanium nitride, zirconia (Oxinium), and titanium Ti6Al-4V alloy [18,23,24].

Conclusions

While there are several theoretical advantages to ceramic-coated TKA components, these are not translating to survivorship benefits within the published literature thus far. With the principal benefit of implant ceramic coating being improved bearing properties, longer term review of these implants is required to see whether they do have advantages over conventional TKAs that cannot be identified within this current follow-up window. However, this series to date demonstrates minimal additional benefits of the ceramic coating.

Conflicts of interest

H. E. Matar gave paid presentations for DePuy Synthes and is a paid consultant for DePuy Synthes. P. J. Radford receives

institutional support from DePuy Synthes, Zimmer Biomet, and Exactech. B. V. Bloch gave paid presentations for DePuy Synthes; is a paid consultant for DePuy Synthes, Ethicon, and Zimmer Biomet; receives research support as a principal investigator from DePuy Synthes; and receives institutional support from DePuy Synthes, Zimmer Biomet, and Exactech. The other 2 authors declare no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.101086.

References

[1] Singh JA, Yu S, Chen L, Cleveland JD. Rates of total joint replacement in the United States: future Projections to 2020-2040 using the national inpatient sample. J Rheumatol 2019;46:1134–40.
[2] Ackerman IN, Bohensky MA, Zomer E, Tacey M, Gorelik A, Brand CA, et al. The projected burden of primary total knee and hip replacement for osteoarthritis in Australia to the year 2030. BMC Musculoskelet Disord 2019;20:90.
[3] 18th annual report for England, Wales, Northern Ireland, the Isle of Man and the States of Guernsey. National Joint Registry for England, Wales, Northern Ireland and the Isle of Man; 2021. https://reports.njrcentre.org.uk [accessed 6.10.22].
[4] Kang C-W, Fang F-Z. State of the art of bioimplants manufacturing: part I. Adv Manufacturing 2018;6:20–40.
[5] Shen G, Zhang J, Kang C, Fang F. Study on surface texture patterns for improving tribological performance of bioimplants. Surf Coat Technol 2021;422:127567.
[6] No authors listed. AS advanced surface ; 7 layers to protect you. Available from https://www.bbraun.com/en/products/b0/as-advanced-surface.html [accessed 6.10.22].
[7] Puente Reyna AL, Fritz B, Schwiesau J, Schilling C, Summer B, Thomas P, et al. Metal ion release barrier function and biotribological evaluation of a zirconium nitride multilayer coated knee implant under highly demanding activities wear simulation. J Biomech 2018;79:88–96.
[8] Reich J, Hovy L, Lindenmaier HL, Zeller R, Schwiesau J, Grupp T. Präklinische Ergebnisse beschichteter Knieimplantate für Allergiker. Der Orthopäde 2010;39:495–502.
[9] Gallo J, Goodman SB, Konttinen YT, Wimmer MA, Holinka M. Osteolysis around total knee arthroplasty: a review of pathogenetic mechanisms. Acta Biomater 2013;9:8046–58.
[10] Madanat R, Laaksonen I, Graves SE, Lorimer M, Muratoglu O, Malchau H. Ceramic bearings for total hip arthroplasty are associated with a reduced risk of revision for infection. Hip Int 2018;28:222–6.
[11] Affatato S, Erani P, Fersini M, Contaldi V, Terrizzi AR, Licciulli A. Preliminary in vitro wear assessment of ceramic cemented femoral components coupled with polyethylene menisci. Materials (Basel) 2021;14:2112.
[12] Oonishi H, Ueno M, Kim SC, Oonishi H, Iwamoto M, Kyomoto M. Ceramic versus cobalt-chrome femoral components; wear of polyethylene insert in total knee prosthesis. J Arthroplasty 2009;24:374–82.
[13] Ezzet KA, Hermida JC, Colwell Jr CW, D'Lima DD. Oxidized zirconium femoral components reduce polyethylene wear in a knee wear simulator. Clin Orthopaedics Relat Research® 2004;428:120–4.
[14] Vertullo CJ, Lewis PL, Graves S, Kelly L, Lorimer M, Myers P. Twelve-year outcomes of an oxinium total knee replacement compared with the same cobalt-chromium design: an analysis of 17,577 prostheses from the Australian orthopaedic association national joint replacement registry. J Bone Joint Surg Am 2017;99:275–83.
[15] Heyse TJ, Chen DX, Kelly N, Boettner F, Wright TM, Haas SB. Matched-pair total knee arthroplasty retrieval analysis: oxidized zirconium vs. Cocrmo Knee 2011;18:448–52.
[16] Stone B, Nugent M, Young SW, Frampton C, Hooper GJ. The lifetime risk of revision following total knee arthroplasty : a New Zealand Joint Registry study. Bone Joint J 2022;104-B:235–41.
[17] Holleyman RJ, Critchley RJ, Mason JM, Jameson SS, Reed MR, Malviya A. Ceramic bearings are associated with a significantly reduced revision rate in primary hip arthroplasty: an analysis from the national joint registry for England, Wales, northern Ireland, and the Isle of Man. J Arthroplasty 2021;36:3498–506.
[18] Grimberg AW, Grupp TM, Elliott J, Melsheimer O, Jansson V, Steinbrück A. Ceramic coating in cemented primary total knee arthroplasty is not associated with decreased risk of revision due to early prosthetic joint infection. J Arthroplasty 2021;36:991–7.
[19] Middleton S, Toms A. Allergy in total knee arthroplasty. Bone Joint J 2016;98:437–41.
[20] Krenn V, Morawietz L, Perino G, Kienapfel H, Ascherl R, Hassenpflug GJ, et al. Revised histopathological consensus classification of joint implant related pathology. Pathol Res Pract 2014;210:779–86.
[21] Matar HE, Porter PJ, Porter ML. Metal allergy in primary and revision total knee arthroplasty. Bone Joint Open 2021;2:785–95.
[22] Gramlich Y, Hofmann L, Kress S, Ruckes C, Kemmerer M, Klug A, et al. Critically high metal ion levels found in metal-on-metal modular hinged knee arthroplasty : a comparison of two different systems. Bone Joint J 2022;104-B:376–85.
[23] Hauer G, Leitner L, Ackerl MC, Klim S, Vielgut I, Ehall R, et al. Titanium-nitride coating does not result in a better clinical outcome compared to conventional cobalt-chromium total knee arthroplasty after a long-term follow-up: a propensity score matching analysis. Coatings 2020;10:442.
[24] Rossi SMP, Perticarini L, Mosconi M, Ghiara M, Benazzo F. Ten-year outcomes of a nitrided Ti-6Al-4V titanium alloy fixed-bearing total knee replacement with a highly crosslinked polyethylene-bearing in patients with metal allergy. Knee 2020;27:1519–24.