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Ceramic-on-Ceramic Bearings in Total Joint Arthroplasty. Part 3

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Summary. *Total hip arthroplasty (THA) currently provides durable long-term outcomes, but osteolysis secondary to polyethylene wear debris remains a fundamental cause of aseptic loosening and revision. Conventional polyethylene failed to provide a suitable bearing for young active patients requiring joint replacement because of the significant demands they place on such bearings. Strategies to reduce friction and wear debris lead to the development of ceramic bearings in THA. The next decade is unlikely to see a paradigm shift in the materials used for THA. Instead, the challenges will be aimed at improving surgical technique in terms of component orientation to improve reproducibility and achieve superior patient outcomes. The optimum bearing surface is one with very low wear rates, a low coefficient of friction, scratch resistance, and is biologically inert. It is also one that can safely accommodate larger femoral head sizes to minimize dislocation rates without damaging the taper junction. Such a material already exists with modern ceramic bearings.*

Key words: *total hip arthroplasty; total knee arthroplasty; ceramics; polyethylene; surface bearing.*

Total hip arthroplasty (THA) currently provides durable long-term outcomes, but osteolysis secondary to polyethylene wear debris remains a fundamental cause of aseptic loosening and revision. Conventional polyethylene failed to provide a suitable bearing for young active patients requiring joint replacement because of the significant demands they place on such bearings. Strategies to reduce friction and wear debris lead to the development of ceramic bearings in THA.

Ceramic head and liner fractures

Ceramic head and liner fractures are associated with massive metallosis and exposure of the local tissues to particles of titanium or cobalt-chromium alloy from the metallic components. Earlier generations of alumina ceramic heads had a reported risk for fracture between 0.26% and 13.4%; however, for newer implants (Biolox Forte), the reported fracture rate is much lower at 0.004 to 0.015% [1]. Fourth-generation alumina delta ceramics now exhibit a fracture risk of 0.002% for the head and 0.02% for the liner, and these typically occur due to malseating prior to impaction [2].

The risk of ceramic liner fracture in new generation ceramic materials has been reported to be between 0% and 5.3%, with a higher incidence among sandwich-type ceramic cups than 1-piece components. Szymanski et al. who reported 5.3% (7/132) of ceramic liner fractures (sandwich type implant) at a mean 32 months after the surgery also revealed clinical risk factors for fracture [3]. These included excessive weight, advanced age, dislocation, prosthetic impingement, and increased postoperative hip offset. In an FDA multicenter study, new composite ceramic materials (Biolox Delta alumina-on-alumina ceramic; one-piece component) exhibited no ceramic fracture within 3 years of follow-up [4]. However, these materials have a relatively short clinical history, so further monitoring is necessary.

Fracture is a catastrophic complication of a ceramic articulation. As discussed, ceramic bearings have evolved over the past four decades. Each generation has shown advancements in terms of manufacturing and composition to address the limitations of the previous iterations. First-generation ceramics had fracture rates of between 10% and 13% [5]. Zirconia ceramics showed greater fracture resistance, but this was offset by inferior wear properties. The reported rate of fracture with BIOLOX forte for both femoral heads and acetabular liners was approximately 0.02% [6].

Squeaking

Another concern remains squeaking of ceramic bearings. This potentially affects the patient's quality of life and survivorship of the implant due to revision of the squeaky hip. Noises emanating from ceramic bearings (usually clicking and squeaking) have been reported with rates that vary from 0% to 33%.

Currently there are several theories on the origin of squeaking but the exact mechanism is still unclear, and is

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likely multifactorial. Some authors reported that squeaky hips are associated with younger active, heavier, and taller patients [7]. Stanat et al. revealed an association with a particular prosthetic design that enabled neck impingement on the metallic rim of the cup [8]. Similarly, Restrepo et al. found a clear relationship between the prevalence of squeaking and the type of femoral component implanted [9]. Alternatively, there are studies that did not report any squeaky hips even after 10 years of follow-up. Other explanations for ceramic-on-ceramic (COC) squeaking include localized "striped" wear, changes of fluid film lubrication conditions, and femoral head microseparation [10]. As a ceramic head passes over the wear stripe, it could generate a vibration and the metallic parts (femoral stem and acetabular shell) amplify this vibration by resonating, resulting in an audible sound. This explanation is consistent with the fact that COC squeaking does not occur until an average of fourteen to eighteen months after surgery. Finally, squeaking could be generated by the rolling/sliding motion of the femoral head inside the liner in the current generation of COC THAs [11]. Manufacturers have introduced acetabular shells with different liner materials that are interchangeable, possibly leading to a diameter mismatch in some cases that allows a rolling/sliding mechanism. Regardless of which theory is plausible, noisy hips can occur in up to 33% of hips with COC bearings; fortunately, clinically the problem is often minor in the majority of patients and revision surgery is indicated only occasionally.

Damage of the ceramic rim

Direct contact between the neck of the stem and the rim of the ceramic liner during range of motion can result in a rim damage. Ceramic fragments can then impose themselves between the ceramic surfaces contributing to accelerated wear. Under some circumstances forceful impingement can even result in dislocation of THA. Stafford et al. revised 6 hips with COC THAs; three of which were revised for impingement-related complications including recurrent dislocation [12].

Survivorship and osteolysis

COC has very low wear rates both for linear and volumetric wear. It is also resistant to third body wear. Excellent clinical outcomes have been observed with COC bearings. Hamilton et al. [13] reported mid-term results of alumina delta COC bearings at 5.3 years follow-up with a mean Harris hip score of 94.4. Kim et al. [14] reported 10-year follow-up in 277 patients of 50 years old, and reported higher survivorship without evidence of osteolysis or ceramic fracture, and excellent patient satisfaction. Studies assessing third-generation alumina forte had previously reported little or no osteolysis at up to 10 years [15]. In addition, Walter et al. [16] reported minimal osteolysis even with bearings in high wear scenarios such as edge loading.

Survivorship studies comparing COC and metal-on-polyethylene (MOP) showed 26% of the patients with conventional polyethylene had osteolysis at 10 years compared with none of the ceramic patients [15]. Survivorship at 10 years comparing COC and metal-on-highly cross-linked polyethylene (MoHXLPE), showed significantly lower wear rates for the ceramic combination [17]. This is attributed to the scratch profile of metal femoral heads that form raised asperities when damaged, which dramatically increased polyethylene wear. A randomized control trial of COC vs. ceramic-on-HXLPE at 10 years by Beaupre et al. [18] shows excellent results for both combinations, but more revisions were seen in the polyethylene group due to dislocation. This may be in part due to the use of smaller 28-mm heads more commonly for CoHXLPE to ensure an adequate depth of polyethylene in smaller acetabular components. Similar results for these bearing combinations have been reported by both Kim et al. [19] and Epinette and Manley [20], with excellent outcome and no osteolysis at 10–12 years.

Head size and dislocation

Ceramic acetabular liners can accommodate larger femoral heads without the concern of increased volumetric wear. These larger heads improve the potential range of motion and have a greater jump distance, theoretically decreasing the dislocation rate. This should be balanced by an appreciation of the reduction in articular arc that can occur with some acetabular shell designs when coupled with ceramic liners. Increased thickness at the base of the ceramic liner can result in lateralization of the center of rotation and consequently reducing the jump distance [21]. The Joint registry of Australia suggests trends toward a lower revision rate with larger head sizes [22]. Attempts to use larger head sizes with newer HXLPE have resulted in reports of rim fracture and brittleness, due to the thinner depth of polyethylene and also by the extent of the cross-linking. These HXLPE liners achieve their cross-linking by undergoing exposure to a variable dose of gas plasma irradiation before re-melting. The dose of radiation aims to permit moderate cross-linking to minimize wear, with only a modest decrease in fatigue strength. Re-melting attempts to eliminate free radicals, but it may affect the ultimate tensile strength and potentially increase the risk of fracture [23].

Noise generation

The use of hard-on-hard bearings has led to reports of noise generation. Squeaking and grinding have been reported in several outcome studies to varying degrees [24]. The typical incidence of squeaking from ceramic bearings is reported to be between 0.5% and 20% [25]. The noise is not associated with pain or functional impairment and its cause is multifactorial (functional component orientation, patient factors, and surgeon factors). The squeaking is believed to be the result of vibrations from intermittent stick–slip friction. Retrieval studies have postulated that edge loading is the cause of this noise generation and is a consequence of suboptimal component placement, impingement, and micro-separation [26].

A study by McDonnell et al. [24] looked at the noise generated from large diameter Delta motion COC bearings and identified 21% of patients reporting squeaking. EBRA analysis of these 206 patients found the noise to be more common in those patients with an increased range of motion, ligamentous laxity, and patients with decreased cup abduction angles and anteversion.

Studies have demonstrated that even radiologically well-positioned implants can exhibit a squeak [24]. The relevance of sagittal pelvic kinematics and its effect on implant orientation during functional activities has been studied [27]. Dynamic imaging pre-operatively may help identify those patients who are at risk of impingement or edge loading during daily activities. Edge loading is not unique to ceramic-on-ceramic bearings. It is equally likely to occur in malorientated impinging MOP or COP bearings producing creep deformation, wear, and potentially late dislocation [28]. Optimum determination of component orientation specific to the patient is likely to significantly reduce this noise phenomenon and further improve the outcome and wear rates of all bearing combinations [29].

Retrieval studies looking at stripe wear in ceramic components observed that even with abnormal contact mechanics, volumetric wear with ceramic was significantly below the threshold that polyethylene bearings must exceed to stimulate osteolysis [30]. Additionally, ceramic wear particle size, even under suboptimal edge-loading conditions, is unable to stimulate macrophage activation and TNF alpha production required for osteolysis due to its size [31]. Analysis of bearings without visible stripes suggests wear rates of o1 µm at up to 30 months from implantation, therefore if edge loading can be prevented with COC bearings then wear could be eliminated [16].

Taper corrosion

Taper corrosion and fretting have been well described in modular hip components [32]. Ceramic is electrochemically inert, so it shows minimal fretting and corrosion compared with matched cohorts of cobalt chrome counter-parts. When fretting is observed with ceramic bearings, it occurs at the apex of the trunnion, and when as metal heads, it occurs around the middle and base [33]. For both these reasons, ceramic heads are less likely to cause trunnionosis and the resultant adverse local reaction that can contribute to the failure of modular metal combinations [34].

Infection

Some early level 3 data has suggested that ceramic bearings have potentially a lower risk of periprosthetic deep joint infection [35]. Caution is required when interpreting such a finding, with compounding variables such as ASA and BMI influencing the data, but the theory is related to the low surface roughness and subsequently reduction in bacterial adhesion.

Health economics

Ceramic bearings result in minimal or no osteolysis and therefore protect against revision surgery for aseptic loosening from wear debris, and the resultant financial implications of these secondary procedures. The only advantage to using MOP is cost, given it exhibits significantly inferior wear characteristics. Surgeons and health economists must ascertain the best implant type for patients of varying activity levels and life expectancy to ensure that hip arthroplasty surgery is cost effective and equitable for all.

Outcomes

Catastrophic failure of an all-ceramic femoral component in a THA has yet to be reported. Clinical trials in the United States that began in the 1990s have not reported an *in vivo* failure of a femoral head.

In a French study, well-functioning alumina THA implants showed no osteolysis at 18.5 years after surgery [36]. At 10-year follow-up after cementless primary THA, another study showed that alumina ceramic-on-ceramic bearings demonstrated a good implant survival rate, good function, a low implant wear rate, and no further radiographic evidence of failure [37]. In a third follow-up study of third-generation ceramic bearings after 10 years, researchers found results that compared favorably with other bearing surfaces [38].

In a study of the 2- to 9-year results of alumina ceramic-on-ceramic THA, Murphy et al. reported that implant survivorship for all hips with aseptic revision of any component was 96% at 9 years, whereas survivorship for hips without previous surgery was 99.3% [39]. The incidence of implant-related complications was 1.7%.

D'Antonio et al., describing the 5-year results of a prospective randomized study comparing alumina ceramic bearings with cobalt-chrome (CoCr)-on-polyethylene (PE) bearings, reported that revision for any reason occurred in 2.7% of the patients with alumina bearings and 7.5% of those with CoCr-on-PE bearings [40]. Osteolysis was reported in 1.4% of the patients with alumina bearings and in 14.0% of those with CoCr bearings. Ceramic bearings had fewer revisions and less osteolysis, and they had no failures at an average follow-up of 5 years.

The largest independent study of ceramic-on-ceramic bearings analyzed data on 223,362 bearings in the National Joint Registry. It concluded that the latest generation of ceramics has reduced the risk of head fracture, but not of liner fracture [41].

Yoo et al., in a study evaluating the clinical and radiological outcomes, ceramic-related complications, and survivorship in 85 patients who underwent 100 cementless THAs with the use of a BIOLOX delta liner–on–BIOLOX forte head articulation at a minimum follow-up of 10 years, reported no fractures of the ceramic liner or head, no measurable ceramic wear, and no pelvic or femoral osteolysis [41].

In a randomized prospective study, Kim et al. compared the long-term (mean follow-up, 17.1 years; range, 15-18) functional, radiographic, and CT scan outcomes and implant survivorship of COC THA versus ceramic-on-highly cross-linked polyethylene THA (COHXLPE THA) in the same 133 patients; all were younger than 55 years of age and each of them underwent COC THA of one hip and COHXLPE THA of the other [42]. Mean Harris hip scores, pain scores, and patient satisfaction scores were comparable in the two groups. No osteolysis was recorded on in either group. Component survival rates were high (>97%) in both groups.

Conflict of interests. The author declares no conflict of interest towards the present article.

References

1. Huet R, Sakona A, Kurtz SM. Strength and reliability of alumina ceramic femoral heads: Review of design, testing, and retrieval analysis. J Mech Behav Biomed Mater 2011;4(3):476-83.

2. Walter WL, O'toole GC, Walter WK, Ellis A, Zicat BA. Squeaking in ceramic-on-ceramic hips: the importance of acetabular component orientation. Journal of Arthroplasty 2007;22:496–503.

3. Szymanski C, Gueriot S, Boniface O, Deladerriere JY, Luneau S, Maynou C. Sandwich type ceramic liner fracture rate with the Atlas III socket: A study of 144 primary total hip replacements at a mean 74 months' follow-up. Orthop Traumatol Surg Res 2011;97(5):494-500.

4. Hamilton WG, McAuley JP, Dennis DA, Murphy JA, Blumenfeld TJ, Politi J. THA with Delta ceramic on ceramic: results of a multicenter investigational device exemption trial. Clin Orthop Relat Res 2010;468(2):358-66.

5. Willmann G. Ceramic femoral head retrieval data. Clinical Orthopaedics and Related Research 2000;379:22–8.

6. Sadoghi P, Pawelka W, Liebensteiner MC, et al. The incidence of implant fractures after total hip arthroplasty. International Orthopaedics 2014; 38:39–46.

7. Sexton SA, Yeung E, Jackson MP, Rajaratnam S, Martell JM, Walter WL, Zicat BA, Walter WK. The role of patient factors and implant position in squeaking of ceramic-on-ceramic total hip replacements. J Bone Joint Surg Br 2011; 93(4):439-42.

8. Stanat SJ, Capozzi JD. Squeaking in third- and fourth-generation ceramic-on-ceramic total hip arthroplasty: meta-analysis and systematic review. J Arthroplasty 2012;27(3):445-53. Epub 2011 Jun 14. Review.

9. Restrepo C, Post ZD, Kai B, Hozack WJ. The effect of stem design on the prevalence of squeaking following ceramic-on-ceramic bearing total hip arthroplasty. J Bone Joint Surg Am 2010;92(3):550-7.

10. Glaser D, Komistek RD, Cates HE, Mahfouz MR. Clicking and squeaking: in vivo correlation of sound and separation for different bearing surfaces. J Bone Joint Surg Am 2008;90 Suppl 4:112-20.

11. Currier JH, Anderson DE, Van Citters DW. A proposed mechanism for squeaking of ceramic-on-ceramic hips. Wear 2010;269(11-12):782-9.

12. Stafford GH, Islam SU, Witt JD. Early to mid-term results of ceramic-on-ceramic total hip replacement: analysis of bearing-surface-related complications. J Bone Joint Surg Br 2011;93(8):1017-20.

13. Hamilton WG, McAuley JP, Dennis DA, et al. THA with Delta ceramic on ceramic results of a multicenter investigational device exemption trial. Clinical Orthopaedics and Related Research 2010;468:358.

14. Kim YH, Park JW, Kim JS. Alumina Delta-on-Alumina Delta bearing in cementless total hip arthroplasty in patients aged 50 years. Journal of Arthroplsty 2016;31(10):2209–14 [pii: S0883-S5403(16)30763-X].

15. D'Antonio JA, Capello WN, Naughton M. Ceramic bearings for total hip arthroplasty have high survivorship at 10 years. Clinical Orthopaedics and Related Research 2012;470:373–81.

16. Walter WL, Insley GM, Walter WK, Tuke MA. Edge loading in third generation alumina ceramic-on-ceramic bearings: stripe wear. Journal of Arthroplasty 2004;19:402–13.

17. Higuchi Y, Hasegawa Y, Seki T, Komatsu D, Ishiguro N. Significantly lower wear of ceramic-on-ceramic bearings than metal-on-highly cross-linked polyethylene bearings: a 10- to 14- year follow-up study. Journal of Arthroplasty 2016;31:1246–50.

18. Beaupre LA, Al-Houkail A, Johnston DW. A randomized trial comparing ceramic-on-ceramic bearing vs ceramic-on-crossfire-polyethylene bearing surfaces in total hip arthroplasty. Journal of Arthroplasty 2016;31:1240–5.

19. Kim YH, Park JW, Kulkarni SS, Kim YH. A randomised prospective evaluation of ceramic-on-ceramic and ceramic-on-highly cross-linked polyethylene bearings in the same patients with primary cementless total hip arthroplasty. International Orthopaedics 2013;37:2131–7.

20. Epinette JA, Manley MT. No differences found in bearing related hip survivorship at 10-12 years follow-up between patients with ceramic on highly cross-linked polyethylene bearings compared to patients with ceramic on ceramic bearings. Journal of Arthroplasty 2014;29:1369–72.

21. Jeffers JR, Roques A, Taylor A, Tuke MA. The problem with large diameter metal-on-metal acetabular cup inclination. Bulletin of the NYU Hospital for Joint Diseases 2009;67:189–92.

22. Mayer SW, Wellman SS, Bolognesi MP, Attarian DE. Late liner disassociation of a Pinnacle system acetabular component. Orthopedics 2012;35:e561–5.

23. McDonnell SM, Boyce G, Bar J, Young D, Shimmin AJ. The incidence of noise generation arising from the large-diameter Delta Motion ceramic total hip bearing. The Bone & Joint Journal 2013;95-B:160–5.

24. Jarrett CA, Ranawat AS, Bruzzone M, et al. The squeaking hip: a phenomenon of ceramic-on-ceramic total hip arthroplasty. The Journal of Bone and Joint Surgery. American Volume. 2009;91-A:1344–9.

25. Walter WL, Kurtz SM, Esposito C, et al. Retrieval analysis of squeaking alumina ceramic-on-ceramic bearings. The Journal of Bone and Joint Surgery. British Volume 2011;93- B:1597–601.

26. Pierrepont JW, Feyen H, Miles BP, Young DA, Baré JV, Shimmin AJ. Functional orientation of the acetabular component in ceramic-on-ceramic total hip arthroplasty and its relevance to squeaking. The Bone & Joint Journal 2016;98-B:910–6.

27. Isaac GH, Dowson D, Wroblewski BM. An investigation into the origins of time- dependent variation in penetration rates with Charnley acetabular cups: wear, creep or degradation? Proceedings of the Institution of Mechanical Engineers, Part H 1996;210:209–16.
28. Spencer-Gardner L, Pierrepont J, Topham M, Baré JV, McMahon S, Shimmin AJ. Patient-specific instrumentation improves the accuracy of acetabular component placement in total hip arthroplasty. The Bone & Joint Journal 2016;98- B:1342–6.
29. Dumbleton JH, Manley MT, Edidin AA. A literature rview of the association between wear rate and osteolysis in total hip arthroplasty. Journal of Arthroplasty 2002;17:649.
30. Hatton A, Nevelos JE, Matthews JB, et al. Effects of clinically relevant alumina ceramic wear particles on TNF-alpha production by human peripheral blood mononuclear phagocytes. Biomaterials 2003;24:1193.
31. Shulman RM, Zywiel MG, Gandhi R, et al. Trunnionosis: the latest culprit in adverse reactions to metal debris following hip arthroplasty. Skeletal Radiology 2015;44:433.
32. Tan SC, Lau AC, Del Balso C, Howard JL, Lanting BA, Teeter MG. Tribocorrosion: ceramic and oxidized zirconium vs cobalt-chromium heads in total hip arthroplasty. Journal of Arthroplasty 2016;31:2064–71.
33. Lindgren JU, Brismar BH, Wikstrom AC. Adverse reaction to metal release from a modular metal-on-polyethylene hip prosthesis. The Journal of Bone and Joint Surgery. British Volume 2011;93(10):1427–30.
34. Pitto RP, Sedel L. Periprosthetic joint infection in hip arthroplasty: is there an association between infection and bearing surface type? Clinical Orthopaedics and Related Research 2016;474:2213–8.
35. Hamadouche M, Boutin P, Daussange J, Bolander ME, Sedel L. Alumina-on-alumina total hip arthroplasty: a minimum 18.5-year follow-up study. J Bone Joint Surg Am. 2002 Jan. 84 (1):69-77.
36. Yeung E, Bott PT, Chana R, Jackson MP, Holloway I, Walter WL, et al. Mid-term results of third-generation alumina-on-alumina ceramic bearings in cementless total hip arthroplasty: a ten-year minimum follow-up. J Bone Joint Surg Am. 2012 Jan 18. 94 (2):138-44.
37. Lau YJ, Sarmah S, Witt JD. 3-rd generation ceramic-on-ceramic cementless total hip arthroplasty: a minimum 10-year follow-up study. Hip Int. 2017 Jul. 29.
38. Murphy SB, Ecker TM, Tannast M. Two- to 9-year clinical results of alumina ceramic-on-ceramic THA. Clin Orthop Relat Res. 2006 Dec. 453:97-102.
39. D'Antonio J, Capello W, Manley M, Naughton M, Sutton K. Alumina ceramic bearings for total hip arthroplasty: five-year results of a prospective randomized study. Clin Orthop Relat Res. 2005 Jul. (436):164-71.
40. Howard DP, Wall PDH, Fernandez MA, Parsons H, Howard PW. Ceramic-on-ceramic bearing fractures in total hip arthroplasty: an analysis of data from the National Joint Registry. Bone Joint J. 2017 Aug. 99-B (8):1012-1019.
41. Kim YH, Park JW. Eighteen-Year Follow-Up Study of 2 Alternative Bearing Surfaces Used in Total Hip Arthroplasty in the Same Young Patients. J Arthroplasty. 2020 Mar. 35 (3):824-830.
42.Yoo JI, Ha YC, Kim DH, Lee YK, Koo KH. Total Hip Arthroplasty Using Hybrid Ceramic Bearing: A Minimum 10-Year Follow-up Study. Indian J Orthop. 2019 Sep-Oct. 53 (5):637-640.

Керамо-керамічні пари тертя в тотальному ендопротезуванні суглобів. Частина 3

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Резюме. *Тотальне ендопротезування кульшового суглоба сьогодні забезпечує довгострокові результати, але остеоліз, що виникає внаслідок зношування поліетилену, залишається основною причиною асептичної нестабільності та ревізії. Звичайний поліетилен не зміг забезпечити відповідний темп зношування для молодих активних пацієнтів, які потребують тотального ендопротезування через значні навантаження, що у таких хворих діють на пари тертя в штучному суглобі. Стратегії зменшення тертя та зношування приводять до розвитку керамічних пар тертя для тотального ендопротезування суглобів. У наступне десятиріччя навряд чи відбудеться зміна парадигми у матеріалах, що використовуються для тотального ендопротезування суглобів. Рішення будуть спрямовані на удосконалення хірургічної техніки з точки зору орієнтації компонентів, щоб покращити умови функціонування ендопротезів і досягти кращих результатів для пацієнтів. Оптимальні поверхні штучного суглоба – це поверхня з дуже низьким рівнем стирання, низьким коефіцієнтом тертя, стійкістю до подряпин і біологічною інертністю. Вони також дають змогу збільшити розмір головки стегнової кістки, щоб мінімізувати частоту вивиху без пошкодження конічного з'єднання голівки і ніжки протеза. Таким матеріалом, що задовольняє сучасні вимоги до суглобових поверхонь штучних суглобів, є сучасна кераміка.*

Ключові слова: *тотальне ендопротезування кульшового суглоба; тотальне ендопротезування колінного суглоба; кераміка; поліетилен; тертя поверхонь.*