Original article
https://doi.org/10.18019/1028-4427-2025-31-5-639-647

Audiogram of ceramic friction noises in total hip arthroplasty and their relationship with acetabular component position

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Abstract

Introduction Noise from a total hip replacement's ceramic friction pair is known as hip squeaking. Acoustic arthrometry in total hip replacement (THR) involves using acoustic emission technology to visualize sound characteristics.

The **objective** was to identify the possibility of identifying noises of a THR ceramic friction pair using the acoustic arthrometry and to determine the relationship of noises with the position of the acetabular component.

Material and methods The retrospective study included 36 patients who underwent THR with a ceramic bearing pair. Seven patients (19.44 %) reported noise at the site of the THR joint. The patients were divided into two groups based on the noise (n = 7) and no noise reported (n = 29). Clinical and radiological parameters were reviewed through online survey considering age, follow-up period, BMI, inclination and anteversion of the acetabular component. Acoustic arthrometry was performed for 10 patients with the pulse height, PEAK, ASYMMETRY and WIDTH measured and compared.

Results Comparative analysis of individual clinical and radiological parameters showed no statistically significant differences in the two groups. However, deviations by any of the two criteria in the acetabular component position was 20.7 % in the no-noise group and 57.1 % in the noise reported group (p = 0.048). Acoustic emission of THR with noise had visual differences in acoustic signature with the mean PEAK measuring 0.492 in the no-noise group and 0.488 in the noise reported group; ASYMMETRY being 0.012 versus 0.015 and WIDTH measuring 479.2 versus 486.5, respectively.

Discussion The findings correlated with the results of previous studies and confirmed the relationship between the angles of the implanted acetabular component and the noise. In contrast to previous studies of acoustic arthrometry, the method offered facilitated objective statistical noise assessment in addition to visualization and analysis of acoustic signatures.

Conclusion The study demonstrated possibilities of acoustic arthrometry in identification of different states of the ceramic friction pair, characterization of the noise detected and its quantification.

Keywords: total hip replacement, ceramic bearings, hip squeaking, acoustic arthrometry

For citation: Tashtanov BR, Pavlov VV, Raifeld MA, Vasyukov VN, Baktyyarov NB, Korytkin AA. Audiogram of ceramic friction noises in total hip arthroplasty and their relationship with acetabular component position. *Genij Ortopedii*. 2025;31(5):639-647. doi: 10.18019/1028-4427-2025-31-5-639-647.

INTRODUCTION

In the 21st century, total hip arthroplasty (THA) is a successful surgical procedure for treating end-stage degenerative hip diseases an optimal treatment for end-stage hip osteoarthritis. Friction-related wear and its consequences are one of the most devastating complications of THA [1]. The history of friction pair materials began with metal-metal progressing to ceramic-polyethylene friction pair [1, 2]. A ceramic-on-ceramic (CoC) total joint replacement was first developed in 1972 by Boutin and presented as wear-resistant and bio-inert with the mass production implemented by the German company Ceramtec [3]. The first generation of the material was characterized by high wear resistance and greater fragility [4]. The shortcomings were addressed with the next generations of ceramics. Fourth-generation ceramic friction material includes an alloy of aluminum oxide and zirconium (Al_2O_3, ZrO_2). Postoperative squeaking can occur in patients who applied the fourth-generation ceramic bearing in total joint replacement [5].

Stanat et al. reported creaking as the most common noise with crunching being the second most common among audible noises [6]. Data extracted from the National Joint Registry for UK, South Korea suggested more stable results with Delta bearings, the rate of ceramic fracture for the liner remained at the same level [7, 8]. More than 88 thousand primary and revision THRs were performed in 2019 in the Russian Federation. CoC friction pair is not commonly used ranging between 0.5 % and 8.2 % of the total THAs performed between 2008 and 2020. Ceramic friction pair is common for patients aged under 30 accounting for 30 % of the total THAs [9]. We can suggest that among these patients there will be those being dissatisfied with THA because of the audible noise.

Total hip replacements (THRs) may occasionally produce vibration and noise [10, 11]. There are studies aimed at exploring audible noises (knocking, creaking, crunching) and inaudible noises (vibrations) that are in ranges beyond the physiological characteristics of the human hearing system, infra- and ultrasound.

The acoustic arthrometry method, based on the acoustic signatures obtained with an accelerometer demonstrated the possibility of detecting loosening of THR implant and destruction of friction pairs, such as Ce–Ce [12]. The method does not rule out a hypothetical possibility of analyzing the acoustic phenomena of solid friction pairs in the infra- and ultrasound ranges, with the subsequent interpretation. In addition to that, the study of noise arising from friction of ceramic pairs of THR provides the prospect of predicting the service life of implants, which is a significant addition to the orthopedic arsenal for assessing the survival of implants at a long term.

The **objective** was to identify the possibility of identifying noises of a THR ceramic friction pair using the acoustic arthrometry and to determine the relationship of noises with the position of the acetabular component.

MATERIAL AND METHODS

Characteristics of patients and THR implants

A retrospective single-center study included 36 patients who underwent THR with a CoC friction pair between 2008 and 2020. The average age of patients was 46 years (18–69) at the time of surgery. There were 23 (64 %) female and 13 (36 %) male patients. The contralateral joint had been previously replaced in 16 (44 %) patients using implants with a metal-polyethylene friction pair and unilateral THR was performed in 20 (56 %) patients.

The participants were informed and signed consent to participate in the study prior to surgery.

The patients were divided into two groups. The first group consisted of patients who had no noise at the THR site ($n = 29$) and the second group included patients who reported audible noise at the THR site ($n = 7$).

The THR surgeries were primary and performed through the anterolateral approach.

The criteria analyzed included age, follow-up period, body mass index (BMI), inclination angle of the acetabular component and anteversion angle of the acetabular component, and reference of the angles with safe zones proposed by Lewinnek (acetabular inclination 45° ± 15° and anteversion 15° ± 10°).

Acoustic arthrometry

The acoustic arthrometry was performed for 10 patients with ceramic THR bearing pair including seven (70 %) patients with complaints of audible noise at the THR site and three patients reporting audible noise which was considered as a normal variant. An acoustic emission recording device equipped with a three-axis accelerometer (IP application, reg. No. 2024134340) was fixed in the projection of the greater trochanter according to the method developed (IP application, reg. No. 2025105401). The subjects were requested to walk a distance of 200 m on a flat surface at a normal individual pace.

The criteria that were used for decoding were developed, substantiated, defined and automated by the staff of the Department of Theoretical Foundations of Radio Engineering of the Federal State Budgetary Educational Institution Novosibirsk State Technical University (Head of Department, MA Raifeld; Professor of Department, VN Vasyukov) [13].

The following criteria were employed for decoding the acoustic signature (Fig. 1):

— pulse heights, designated by conventional units 0, 1, 2, 3…;

— PEAK, pulse distortion with threshold value < 0.49;

— ASYMMETRY, pulse asymmetry reflecting component wear with threshold value > 0.02;

— WIDTH, pulse width representing the looseness or destruction of components with a threshold > 500.

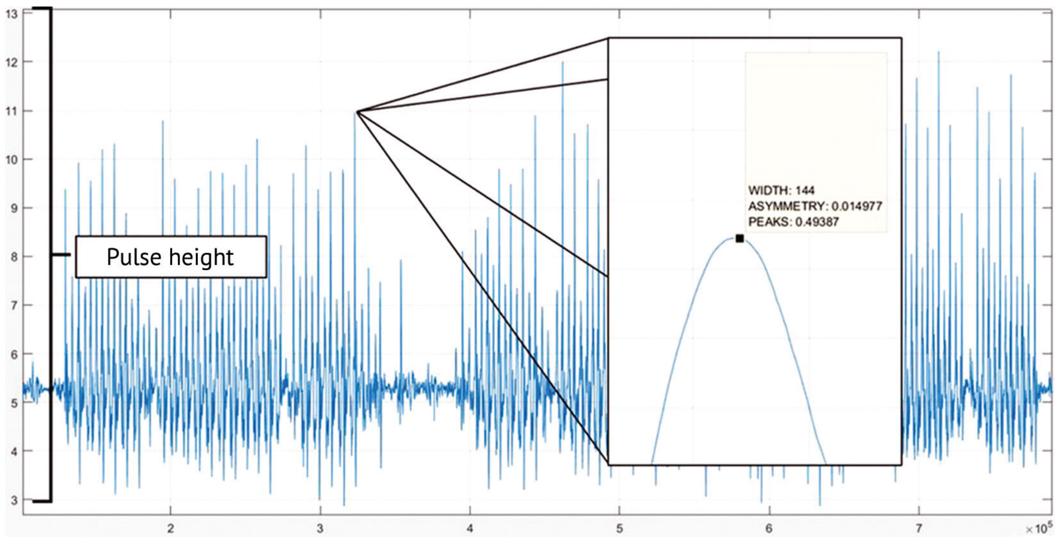

Fig. 1 Acoustic signature evaluation criteria. The rectangle shows a selectively taken normal pulse of the acoustic signature of ceramic pair friction (marked with converging black lines), which can be analyzed using the criteria offered: height, 11 units; PEAK, 0.49387; ASYMMETRY, 0.014977; WIDTH, 144

The acoustic signature analysis was performed using MATLAB software. The device mechanism was described in details in our previous work [13].

Statistical analysis

Python programming language (version 3.11) was used for data analysis. The mean and the range were estimated for quantitative variables of the two groups (age, follow-up time, BMI, inclination and anteversion of the acetabular component). The Student's t-test was used for independent samples and the Mann–Whitney U-test employed for the data violating the assumption of normal distribution. The Fisher exact test was used for categorical variables. The level of statistical significance was set at $p < 0.05$.

RESULTS

The survey and analysis of the findings indicated the noise in seven patients at the THR joint replaced with a ceramic friction pair, which corresponded to 19.44 % of the sample (7 out of 36). Three of the seven patients reported the noise being heard by themselves and by people nearby, the remaining four patients heard the noise by themselves only. 29 (80.56 %) patients in the group reported no noise at the THR site.

A comparative analysis of clinical and radiological parameters of the two groups revealed no statistically significant differences (Table 1).

Table 1

Parameters of patients in two groups divided by the presence or absence of audible noise

Description	Group I (no noise)	Group II (noise reported)	*p*-value
	n = 29; 80.56 %	*n* = 7; 19.44 %	
Age, years	51.17 ± 14.98	52.57 ± 10.89	0.779
BMI, kg/m^2	26.75 ± 4.32	26.32 ± 4.39	0.794
Follow-up period, years	6.20 ± 1.63	5.29 ± 1.30	0.089
Χυπ ινχλινατιον, °	42.00 ± 7.02	38.00 ± 9.59	0.181
Χυπ αντεϖερσιον, °	12.63 ± 8.35	11.80 ± 4.30	0.758

The reference of the inclination angle of the acetabular component with the reference values (45 ± 15)° was reviewed. Deviation from the reference was detected in 17.2 % of cases of the first group of patients (no noise at the THR site) and in 42.9 % of the second group (noise reported). Deviations from the reference anteversion values proposed by Lewinnek (15 ± 10)° were detected in 13.8 % of cases in the noise-free group and in 28.6 % of cases in the noise-reported group. No statistically significant difference was found in any of the individual indicators. A significant difference was found in the percentage ratio of the total number of deviations in both angles of implantation of the acetabular component in the no-noise group: 20.7 % versus 57.1 % in the reported noise group (Table 2). The results of the study showed that deviation from the reference angles of implantation of the acetabular component can be associated with the occurrence of the noise.

Table 2

Comparative analysis of the deviation rates from the conventional norm of inclination and anteversion of the acetabular component in two groups divided by the "presence or absence" of audible noise

Description	Group I (no noise)		Group II (noise reported)		*p*-value
	n = 29; 80.56 %		*n* = 7; 19.44 %		
	abs.	%	abs.	%	
Deviation in inclination	5	17.2	3	42.9	0.145
Deviation in anteversion	4	13.8	2	28.6	0.290
Deviation in any criterion	6	20.7	4	57.1	0.048*

Acoustic arthrometry analysis

Acoustic emission of implants with audible noise had significant visual differences in the distorted acoustic signature (Fig. 2). The pulse height did not exceed 10 c.u. in average values in the second group with noise (*n* = 7) and the pulse height exceeded 10 c.u. in average values in the no-noise group (*n* = 3) with the audiogram taken as a conditional norm (red line, Fig. 2a). The average value of the PEAK was 0.492 in the no-noise group and 0.488 in the group with audible noise, ASYMMETRY was 0.012 versus 0.015, WIDTH measured 479.2 versus 486.5.

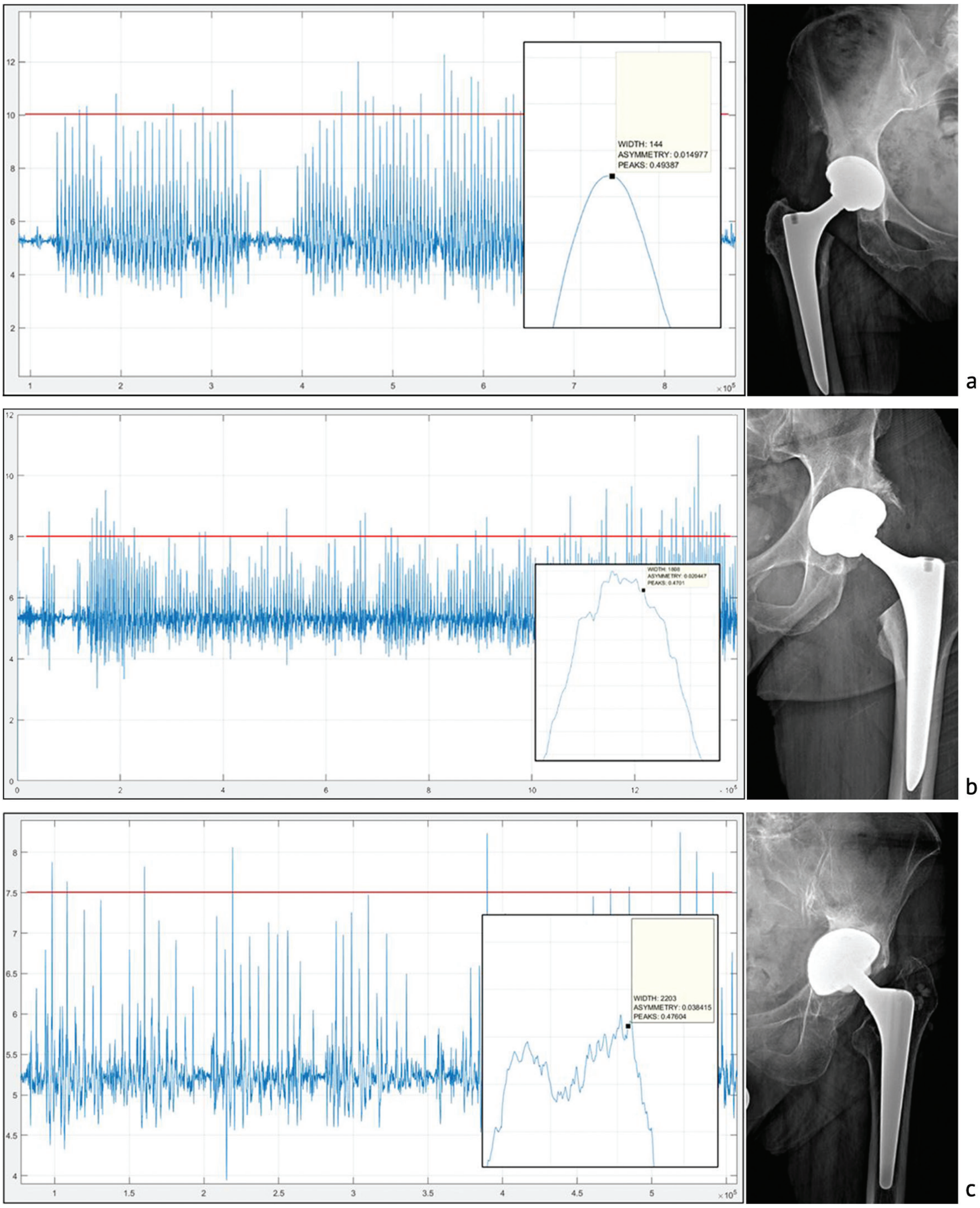

Fig. 2 General view of acoustic signatures showing individual pulse peaks and AP radiographs of the hip joint: (a) no noise, no loosening of the THA; inclination and anteversion of the acetabular component measuring 40° and 12°, correspondingly; (b) noise being reported (creaking), no THA loosening with inclination and anteversion of the acetabular component measuring 30° and 7°; (c) — with noise (crunch) and loosening (prolapse) of the acetabular component

Examination of the acoustic signature suggested requires an analysis of the overall graph picture and the pulse height (normally ⩾ 10.0 units) at the first stage regardless of the thickness of the soft tissues. The second stage involves an analysis of the Peak criterion (normally ⩾ 0.49 units). A value below the specified threshold indicated a violated congruence of the friction surface. The third stage involved the analysis of the ASYMMETRY criterion (⩽ 0.0200 units). A value obtained above the specified one indicated the destruction of the friction pair components. WIDTH was the fourth criterion to be analyzed with the normal values corresponding to ⩽ 500 units. One of the components was considered to be loose with the value being greater.

DISCUSSION

Our pilot study had limitations related to the fact that the sample of patients who underwent acoustic arthrometry was limited to 10 patients out of 36 with seven patients reporting audible noise of the ceramic friction pair, and the audiograms of three patients out of 29 patients reporting no noise were accepted as the norm. In terms of time, the use of ceramics in THA is relatively new compared to other bearing pairs. Considering the longevity of the THA, the bearing pair can be recommended for implantation in younger patients [14]. This is due to their active lifestyle and its duration relative to other age groups. Orthopaedic surgeons are to be more selective in the candidates for the friction pair or refuse it in favor of a polyethylene-ceramic friction pair.

No statistically significant differences in age, BMI, follow-up periods or acetabular component implantation angles were found in the series between the groups. However, a difference was recorded in the percentage of the total number of deviations in the comparison groups confirming the effect of adequate placement of the acetabular component on the occurrence of noise [5, 15, 16]. The number of patients who developed noise at the THA site varied from 3 % to 30 % [5, 15, 17]. The results of our study correlate with the data obtained by other authors.

The fact of the technical possibility of recording vibrations arising from friction of a ceramic pair in THA during movement contributes to the detailing of the sound signature depending on the type of ceramic, head size, inclination angle and anteversion of the acetabular component in the infrasound and ultrasound ranges. We were the first in the world who described vibrations occurring in the ceramic friction pair in the group of patients using our patented device. The findings would open up great opportunities for exploring audible noise, inaudible noise (vibrations), which theoretically should not exist in a solid and congruent ceramic friction pair since there is no dry friction, and the peaks of the pulses must be symmetrical and uniform. Noise alone can be perceived as an insignificant undesirable phenomenon, since it is not accompanied by pain and patients might neglect it. The noise can be associated with significant destruction (dry friction) of the ceramic friction pair [18]. The patient can resolve the problem of an "acceptable" noise (impact or load on the rear edge of the liner during excessive flexion) by limiting the volume of certain causal movements (favorable prognosis) [19]. If the noise results from the edge loading (ceramic head on the edge of the ceramic liner in a standing position), it is "unacceptable" and cannot be eliminated by preventive measures on the part of the patient. The consequences of "unacceptable" noise can be significant (unfavorable prognosis), including ceramic fracture and migration of ceramic debris into soft tissues, which is difficult to address during revision surgeries [20].

Lucchini et al. suggested that noise may be a sign of failed ceramic materials of the components and can lead to multi-stage destruction of the friction pair [21]. The event can lead to a complicated revision surgery requiring careful removal of the debris from the surrounding soft tissues.

The debris can spread chaotically with destroyed ceramic friction pair despite careful removal of ceramics from soft tissues with a risk of a repeated injury to revision ceramic friction pairs (liner/head) with remaining ceramic fragments (third body), and implantation of a polyethylene liner can be associated with early wear and tear and osteolysis of the bone tissue. Acoustic arthrometry, as a non-invasive and safe method, enables continuous monitoring of the implant with a ceramic friction pair.

Wakayama [22] and Yamada [23] were the first to suggest acoustic emission for diagnosis of microcracks in a rubbing ceramic surface, and experimentally proved that the increase in emission pulses (hits/impacts) corresponds to the moment of ceramic splitting. Analysis of the acoustic emission of friction pairs, including ceramic pairs, accompanied by video fluoroscopy was performed by Glaser et al. who reported a direct correspondence between the vibrations recorded with arthrometry and the movements in the prosthetic joint, including a correlation of changes in the presence of creaking, crunching and other noises [24]. Roffe et al. suggested that in CoC THA the recordable noise of a hip squeak in 82 joints did not originate nor had contribution from the trunnion morse taper connection [25]. In addition to that, the authors found that magnitude of emission may decrease depending on the thickness of the subcutaneous fat tissue with no changes in the number and frequency of oscillations.

Kummer et al. performed a study on 98 patients and found that the graph (acoustic signature) was subject to distortion depending on implant stability and integrity of the friction pair surface [26], which is consistent with our results. As shown in Figure 2, the acoustic signature depends on the stability of the components and is characterized by the absence of sharp and chaotic fluctuations. Rodgers et al. discovered and experimentally confirmed the difference in the pitch of acoustic emissions of various noises. Creaking differed from crunching and knocking by a high and prolonged oscillation, while crunching was characterized by a low frequency, and knocking by intermittency [27, 28]. New statistical units of measurement we offered for our research method include PEAK, ASYMMETRY and WIDTH to represent the nature of oscillation distortion, which will be practical for a physician to perceive information in an acoustic signature.

CONCLUSION

Проведенное The pilot study opens up prospects and possibilities for the application of the acoustic arthrometry to allow identification of the ceramic friction pair status standardizing noise measurement, characterizing the detected noise and measuring it in quantities. Description of noise by numerical values (quantities) will allow for a comparative analysis of noise with retrieving statistical data and correlation links and identifying the initial signs of destruction of the friction pair to facilitate early measures and prevent adverse events and complications.

Conflict of interests *The authors declare that there is no conflict of interest..*

Funding *The authors received no specific funding for this work.*

Ethical Approval *Not required.*

Informed consent *The patients gave informed consent for publication of the findings without identification.*

REFERENCES

1. Callaghan JJ, Cuckler JM, Huddleston JI, et al. How have alternative bearings (such as metal-on-metal, highly cross-linked polyethylene, and ceramic-on-ceramic) affected the prevention and treatment of osteolysis? *J Am Acad Orthop Surg*. 2008;16 Suppl 1:S33-S38. doi: 10.5435/00124635-200800001-00008.

2. Shubnyakov II, Tikhilov RM, Goncharov MY, et al. Merits and demerits of modern bearing surfaces of hip implants (review of foreign literature). *Traumatology and Orthopedics of Russia*. 2010;16(3):147-156. (In Russ.) doi: 10.21823/2311-2905-2010-0-3-147-156.
3. Boutin P. Total arthroplasty of the hip by fritted aluminum prosthesis. Experimental study and 1st clinical applications. *Rev Chir Orthop Reparatrice Appar Mot*. 1972;58(3):229-246.
4. Hannouche D, Nich C, Bizot P, et al. Fractures of ceramic bearings: history and present status. *Clin Orthop Relat Res*. 2003;(417):19-26. doi: 10.1097/01.blo.0000096806.78689.50.
5. Zhao CC, Qu GX, Yan SG, Cai XZ. Squeaking in fourth-generation ceramic-on-ceramic total hip replacement and the relationship with prosthesis brands: meta-analysis and systematic review. *J Orthop Surg Res*. 2018;13(1):133. doi: 10.1186/s13018-018-0841-y.
6. 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):445-453. doi: 10.1016/j.arth.2011.04.031.
7. Holleyman RJ, Critchley RJ, Mason JM, et al. 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(10):3498-3506. doi: 10.1016/j.arth.2021.05.027.
8. Yoon BH, Park JW, Cha YH, et al. Incidence of ceramic fracture in contemporary ceramic-on-ceramic total hip arthroplasty: a meta-analysis of proportions. *J Arthroplasty*. 2020;35(5):1437-1443.e3. doi: 10.1016/j.arth.2019.12.013.
9. Shubnyakov II, Riahi A, Denisov AO, et al. The main trends in hip arthroplasty based on the data in the Vreden's Arthroplasty Register from 2007 to 2020. *Traumatology and Orthopedics of Russia*. 2021;27(3):119-142. (In Russ.) doi: 10.21823/2311-2905-2021-27-3-119-142.
10. Tashtanov BR, Rajfeld MA, Vasyukov VN, et al. Feasibility of vibration arthrometry in hip arthroplasty: a review. *Traumatology and Orthopedics of Russia*. 2025;31(1):133-143. (In Russ.) doi: 10.17816/2311-2905-17552.
11. Lee C, Zhang L, Morris D, et al. Non-invasive early detection of failure modes in total hip replacements (THR) via acoustic emission (AE). *J Mech Behav Biomed Mater*. 2021;118:104484. doi: 10.1016/j.jmbbm.2021.104484.
12. FitzPatrick AJ, Rodgers GW, Hooper GJ, Woodfield TB. Development and validation of an acoustic emission device to measure wear in total hip replacements in-vitro and *in-vivo*. *Biomed Signal Process Control*. 2017;33:281-288. doi: 10.1016/j.bspc.2016.12.011.
13. Vasyukov VN, Raifeld MA, Sokolova DO, et al. Processing and analysis of signals for diagnosing the condition of a hip joint endoprosthesis. *Proceedings of the Russian higher school Academy of sciences*. 2024;(4):48-63. (In Russ.)
14. Atrey A, Wolfstadt JI, Hussain N, et al. The ideal total hip replacement bearing surface in the young patient: a prospective randomized trial comparing alumina ceramic-on-ceramic with ceramic-on-conventional polyethylene: 15-year follow-up. *J Arthroplasty*. 2018;33(6):1752-1756. doi: 10.1016/j.arth.2017.11.066.
15. Shah SM, Deep K, Siramanakul C, et al. Computer navigation helps reduce the incidence of noise after ceramic-on-ceramic total hip arthroplasty. *J Arthroplasty*. 2017;32(9):2783-2787. doi: 10.1016/j.arth.2017.04.019.
16. Sarrazin J, Halbaut M, Martinot P, et al. Are CPR (Contact Patch to Rim) distance anomalies associated with the occurrence of abnormal noises from ceramic-on-ceramic THA? *Orthop Traumatol Surg Res*. 2023;109(1):103438. doi: 10.1016/j.otsr.2022.103438.
17. McDonnell SM, Boyce G, Baré J, et al. The incidence of noise generation arising from the large-diameter Delta Motion ceramic total hip bearing. *Bone Joint J*. 2013;95-B(2):160-165. doi: 10.1302/0301-620X.95B2.30450.
18. Tashtanov BR, Kirilova IA, Pavlova DV, Pavlov VV. Ceramic-related noise as an adverse outcome in total hip arthroplasty. *Genij Ortopedii*. 2023;29(5):565-573. doi: 10.18019/1028-4427-2023-29-5-565-573.
19. Walter WL, Insley GM, Walter WK, Tuke MA. Edge loading in third generation alumina ceramic-on-ceramic bearings: stripe wear. *J Arthroplasty*. 2004;19(4):402-413. doi: 10.1016/j.arth.2003.09.018.
20. Tashtanov BR, Korytkin AA, Pavlov VV, Shubnyakov II. Ceramic liner fracture in total hip arthroplasty: a case report. *Traumatology and Orthopedics of Russia*. 2022;28(3):63-73. doi: 0.17816/2311-2905-1804.
21. Lucchini S, Baleani M, Giardina F, et al. A case-driven hypothesis for multi-stage crack growth mechanism in fourth-generation ceramic head fracture. *J Orthop Surg Res*. 2022;17(1):293. doi: 10.1186/s13018-022-03190-6.
22. Wakayama S, Jibiki T, Ikeda J. Quantitative detection of microcracks in bioceramics by acoustic emission source characterization. *J Acoustic Emission*. 2006;24:173-179.
23. Yamada Y, Wakayama S, Ikeda J, Miyaji F. Fracture analysis of ceramic femoral head in hip arthroplasty based on microdamage monitoring using acoustic emission. *J Mater Sci*. 2011;46:6131-6139. doi: 10.1007/s10853-011-5578-5.
24. 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 4:112-120. doi: 10.2106/JBJS.H.00627.

25. Roffe L, FitzPatrick AJ, Rodgers GW, et al. Squeaking in ceramic-on-ceramic hips: no evidence of contribution from the trunnion morse taper. *J Orthop Res*. 2017;35(8):1793-1798. doi: 10.1002/jor.23458.
26. Kummer F, Jaffe WL. Feasibility of using ultrasonic emission for clinical evaluation of prosthetic hips. *Bull NYU Hosp Jt Dis*. 2010;68(4):262-265.
27. Rodgers GW, Young JL, Fields A V, Shearer RZ, et al. Acoustic Emission Monitoring of Total Hip Arthroplasty Implants. *IFAC Proceedings Volumes*. 2014;47(3):4796-4800. doi: 10.3182/20140824-6-ZA-1003.00928.
28. Rodgers GW, Welsh RJ, King LJ, et al. Signal processing and event detection of hip implant acoustic emissions. *Control Engineering Practice*. 2017;58:287-297. doi: 10.1016/J.CONENGPRAC.2016.09.013.

The article was submitted 30.05.2025; approved after reviewing 11.08.2025; accepted for publication 25.08.2025.

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