Ima *et al. BMC Musculoskeletal Disorders* (2025) 26:188
https://doi.org/10.1186/s12891-025-08445-x

BMC Musculoskeletal Disorders

RESEARCH

Open Access

Influence of stem length on sagittal alignment in total hip arthroplasty: a comparison between short and standard stems

Musashi Ima[1], Tamon Kabata[1*], Daisuke Inoue[1], Yuu Yanagi[1], Takahiro Iyobe[1] and Satoru Demura[1]

Abstract

Background Total hip arthroplasty (THA), a critical surgery for hip joint pain relief and mobility restoration, involves careful consideration of various factors, including stem length. Short stems are often chosen for their potential to reduce tissue damage and thigh pain. Precise alignment is necessary to alleviate complications such as stem loosening and fractures. We aimed to compare intramedullary insertion freedom and alignment changes between short and standard stems in THA. This study is based on preoperative planning simulations, highlighting the potential clinical implications.

Methods This retrospective study involved 102 hip joints (34 each from Dorr A, B, and C) undergoing initial THA between 2015 and 2017. A preoperative computed tomography scan was used to create three-dimensional bone models for planning virtual surgery, assessing stem insertion in flexion/extension, and measuring the anterior femoral offset. One-way repeated-measures analysis of variance was conducted to compare intramedullary insertion freedom and anterior femoral offset across the three Dorr classifications (A, B, and C). A paired t-test was used to compare intramedullary insertion freedom and anterior femoral offset between short and standard stems for each Dorr classification and between different medullary shapes.

Results Statistically significant differences were observed between the stem types ($p < 0.05$). Short stems demonstrated significantly greater intramedullary insertion freedom, with averages of 7.5°, 8.2°, and 9.1° for Dorr A, B, and C, respectively, compared with 4.3°, 5.0°, and 5.8° for standard stems. Additionally, the anterior femoral offset was significantly higher in short stems, with an average increase of 2.5 mm across classifications, compared to 1.2 mm in standard stems ($p < 0.05$).

Conclusion Short stems offer enhanced intramedullary insertion freedom and improved anterior femoral offset, potentially leading to better alignment outcomes in THA. However, their increased freedom necessitates precise surgical planning, particularly in patients with wider medullary morphologies. These findings emphasize the importance of simulation-based planning in understanding the impact of stem length, while clinical studies are needed to validate these results.

*Correspondence:
Tamon Kabata
tamonkabata@yahoo.co.jp

Full list of author information is available at the end of the article

Keywords Total hip arthroplasty (THA), Short femoral stem, Anterior femoral offset (AFO), Intramedullary insertion freedom, Sagittal alignment, Dorr classification

Background

Ensuring a good postoperative range of motion (ROM) without bone and implant impingement is crucial in total hip arthroplasty (THA) to avoid complications. However, while securing an adequate ROM, it is important to avoid increasing the risk of complications such as dislocation, stem loosening, or fractures, a complication influenced by various factors. Improper implant alignment or inappropriate size selection may contribute to mechanical imbalance, potentially increasing the risk of dislocation. Therefore, selecting an implant size that closely matches the patient's anatomical features, along with ensuring proper alignment and positioning during surgery, are crucial for reducing these risks. Proper implant alignment and size selection may reduce the risk of dislocation, but further evidence is required to establish this relationship. These factors are particularly important when selecting implants to match the patient's anatomical features. Moreover, implants that are either excessively large or small can result in joint instability. Similarly, surgical techniques that ensure precise placement and orientation of the implant are crucial because poorly aligned implants can increase the likelihood of dislocation. In addition, patient-specific factors such as bone quality and anatomical characteristics also play an important role. In patients with weaker bone quality or unique bone shapes, careful selection and placement of the implant is crucial. Therefore, a comprehensive consideration of these factors is essential to reduce complications and improve outcomes in THA.

Misalignment of the femoral stem during THA can lead to issues such as stem loosening, femoral fractures, and femoral stem subsidence [1–3]. Notably, minimally invasive THA techniques, including implant insertion through small incisions, which preserve the bone and soft tissue, have been developed in recent years and have become the standard methods of choice [4]. Short femoral stems are increasingly being used in THA because of their potential to reduce blood loss and facilitate soft tissue and bone preservation during surgery compared with standard stems [5, 6]. Furthermore, a short femoral stem is associated with reduced postoperative thigh pain [7] and can promote proximal load stress transmission and decrease stress shielding [8]. Short femoral stems also offer a limited bone-reaming range during implant removal, facilitating easier implant fixation during revision surgery [9].

Malalignment of the short femoral stem can easily lead to stress shielding [10], and inappropriate size selection may result in an increased incidence of subsidence [11]. Moreover, movement of the femoral head center affects the ROM after THA [12]. Therefore, achieving correct alignment when using a short femoral stem is necessary. To the best of our knowledge, no study has yet examined the differences between short and standard femoral stems in terms of the flexion/extension insertion range and the resulting changes in anterior femoral offset (AFO). Therefore, the present study aimed to evaluate these differences and relationships and clarify the influence of femoral stem sagittal tilt on bone morphology, flexion/extension insertion range, and AFO using a computerized tomography (CT) -based simulation.

Methods

Patients & ethics approval

This study adhered to the principles of the Declaration of Helsinki. The need for ethics approval was waived by the Medical Ethics Committee of Kanazawa University according to the "Ethical Guidelines for Medical and Health Research Involving Human Subjects" provided by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of Health, Labour and Welfare (MHLW) in Japan. Written informed consent was obtained from all participants. Confidentiality and anonymity were ensured, and participants were informed of their right to withdraw at any time.

In this retrospective simulation study, preoperative CT data were obtained from patients who underwent their first THA at our hospital between March 2015 and December 2017. Femurs were classified into Dorr A, B, and C categories based on preoperative radiographic findings, following Dorr's classification system, which categorizes femoral bone quality and shape into three types based on cortical thickness and medullary canal width [13] (Fig. 1). Patient demographics are presented in Table 1.

The study involved 102 hips, and no significant differences were observed in age, height, weight, BMI, underlying disease, and sex among Dorr A, B, and C groups (Table 1).

CT scanning and three-dimensional (3D) reconstruction

This study was entirely simulation-based, utilizing preoperative CT scans to create 3D models for virtual planning. Preoperative CT scans were obtained from the iliac crest to the femoral condyle, and the data were imported into CT-based templating software (ZedHip; Lexi, Tokyo, Japan) to create virtual 3D bone models for preoperative planning simulations [14].

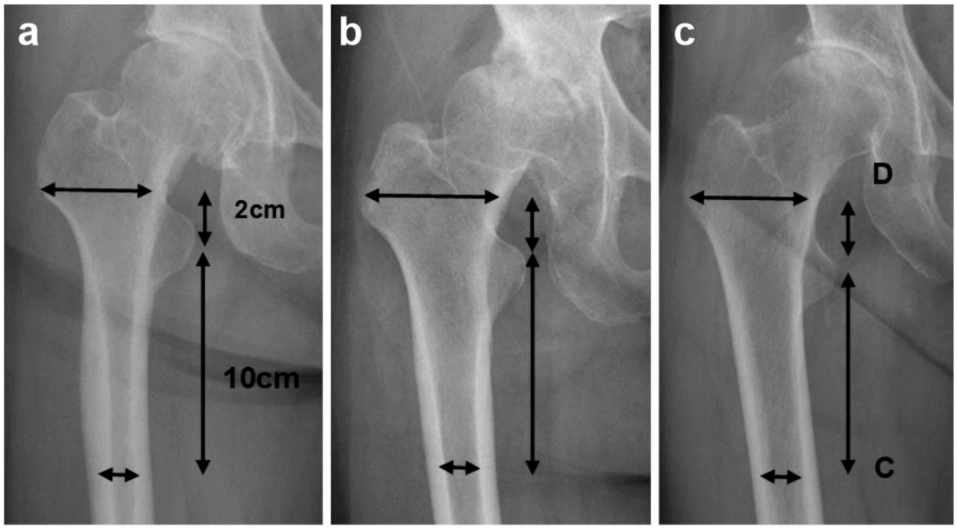

Fig. 1 The Canal Flare Index (CFI) is a metric used to categorize the shape of the femoral canal based on the measurement of the canal diameter at a point 2 cm above the lesser trochanter relative to the diameter at the narrowest part, known as the isthmus. A high CFI, exceeding 4.7, indicates a "Champagne flute" shape, a CFI between 3 and 4.7 corresponds to a "normal" femoral canal, and a CFI lower than 3 suggests a "Stovepipe" configuration

Table 1 Demographic data of the patients

	Dorr A	Dorr B	Dorr C	*P*-value
Age (years)	59.2 ± 10.8	61.4 ± 9.7	62.4 ± 13.6	0.13
Sex (female/male)	29/5	28/6	22/12	0.08
Disease (OA/ONFH)	32/2	30/4	31/3	
Height (cm)	155.6 ± 8.1	154.4 ± 8.3	156.4 ± 9.6	0.68
Weight (kg)	58.5 ± 14.1	55.4 ± 18.3	56.1 ± 12.1	0.66
BMI	24.1	23.2	22.8	0.61

OA, osteoarthritis; ONFH, osteonecrosis of the femoral head; BMI, body mass index

Coordinate system definition

The pelvic position was standardized according to the functional pelvic plane [15]. The coordinate system of the femur was defined based on the femoral posterior condylar plane formed by the posterior, lateral, and medial condyles [16]. Native femoral anteversion was measured in this coordinate system, according to the method described by Sugano et al. [17].

Femoral stem insertion simulation

Femoral stems were classified based on Feyen's classification [18] and further categorized according to length. All measurements and comparisons were conducted within the framework of virtual simulations, without any intraoperative or postoperative clinical data being incorporated. For the insertion simulation, Taperloc Complete (Zimmer Biomet, Warsaw, IN, USA) stems were used to represent standard femoral stems, and Taperloc Microplasty (Zimmer) stems were used to represent short femoral stems. A 32-mm head was used in all cases. While positioning the implant, the axis of the femoral stem was precisely aligned with the center of the original femoral diaphysis. Additionally, anteversion was consistently adjusted to match the natural neck rotation of the femur in all cases (Fig. 2).

Intramedullary insertion freedom of intramedullary stem

While preserving the original femoral anteversion, the stem was moved from its initial position along the proximal femoral axis in the flexion/extension direction. The point at which the femur collided with the stem in either maximum flexion or extension was defined as the maximum flexion or extension angle, respectively. The range within which the stem could be inserted in the flexion/extension position with the original femoral anteversion maintained was defined as the freedom of intramedullary insertion.

Measurement of AFO

The anterior distance (AFO) from the posterior condylar plane to the center of the femoral head was measured to evaluate the anteroposterior distance from the posterior condylar plane to the center of the femoral head (Fig. 3) [19].

Data analyses

Statistical analyses were performed using SPSS version 26 (IBM Corp., Armonk, NY, USA). One-way repeated-measures analysis of variance was used to analyze and compare intramedullary insertion freedom and AFO between the groups. The intramedullary insertion freedom and AFO between the short and standard stems and the intramedullary insertion freedom and medullary shape were compared using a paired *t*-test. Results with $P < 0.05$ were considered significant.

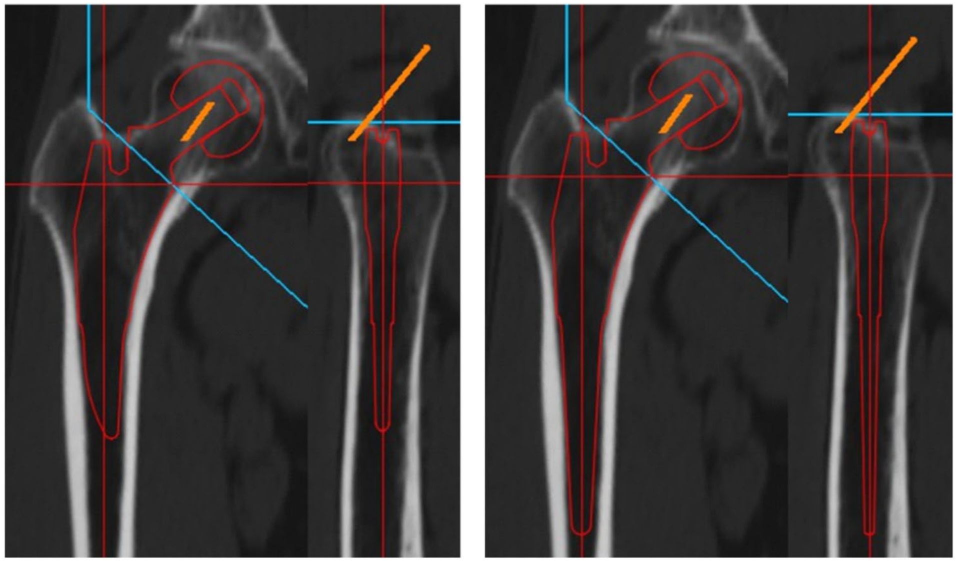

Fig. 2 The stem was inserted to fit the femoral medullary cavity morphology, and the original leg length was reproduced by changing the stem insertion depth and neck length. The stem was inserted midway into the proximal femoral medullary cavity, and this position was used as the initial position

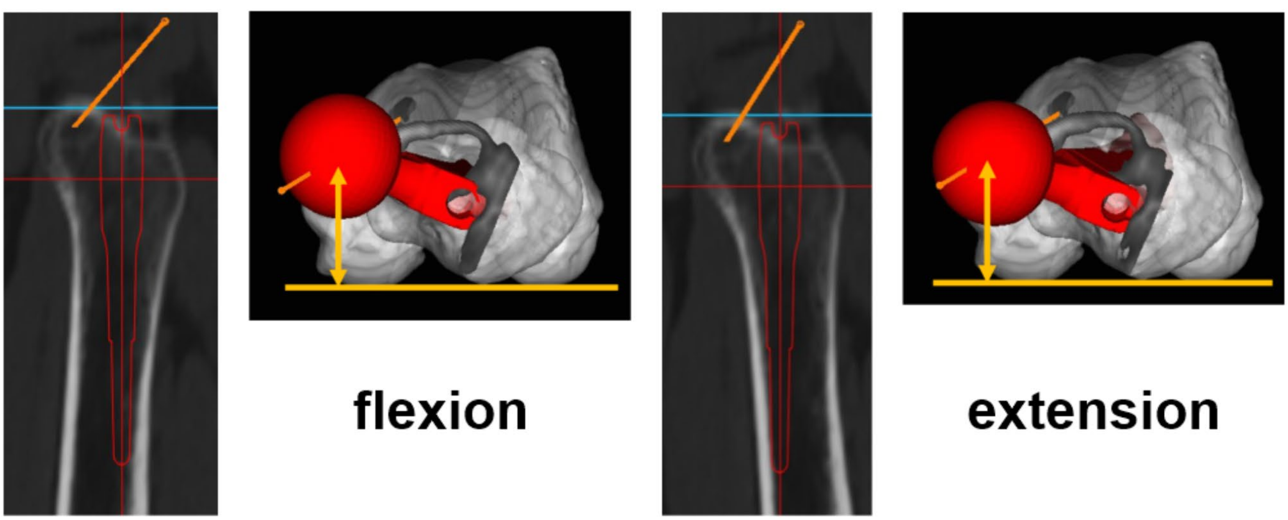

Fig. 3 The anterior distance from the posterior condylar plane to the center of the femoral head (anterior femoral offset) was measured to evaluate the anteroposterior distance from the posterior condylar plane to the center of the femoral head

Results

Table 1 presents the patients' demographic data. We compared the intramedullary insertion freedom and AFO between the short and standard stems for each medullary shape. In terms of intramedullary insertion freedom, Dorr A (short stem average 5.7, standard deviation[SD] 2.0, range 3.0–8.2; standard stem average 3.4, SD 1.3, range 1.0–5.4), Dorr B (short stem average 6.7, SD 1.6, range 4.0–9.0; standard stem average 3.7, SD 1.4, range 1.3–6.1), and Dorr C (short stem average 7.5, SD 1.8, range 5.2–9.6; standard stem average 4.5, SD 1.5, range 2.0–7.6) showed significantly greater intramedullary insertion freedom with the short stem than with the standard stem for all medullary shapes ($P < 0.05$; Fig. 4).

Similarly, in terms of AFO, Dorr A (short stem average 2.8, SD 1.0, range 1.2–4.7; standard stem average 1.9, SD 0.8, range 0.7–2.9), Dorr B (short stem average 3.3, SD 1.9, range 1.3–4.9; standard stem average 1.9, SD 0.9, range 0.9–3.0), and Dorr C (short stem average 3.6, SD 2.0, range 1.4–6.1; standard stem average 2.1, SD 1.0, range 1.0–3.2) showed significantly greater intramedullary insertion freedom with the short stem than with the standard stem for all medullary shapes ($P < 0.05$; Table 2).

Intramedullary insertion freedom increased as the medullary shape approached a stovepipe type in the order Dorr A < B < C for short and standard stems (Fig. 4).

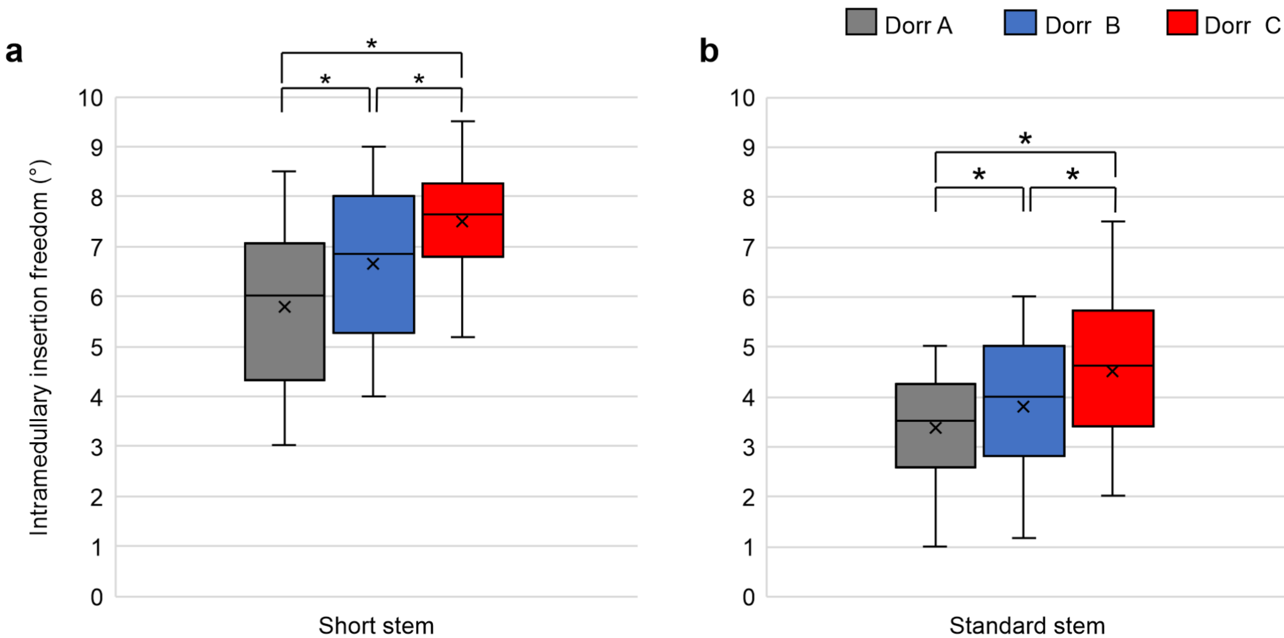

Fig. 4 Graph showing the anterior distance from the retrocondylar plane (anterior femoral offset) of the (**a**) short stem and (**b**) standard stem. A single asterisk (*) indicates $p < 0.05$

Table 2 Anterior femoral offset of the short and standard stems for each medullary shape

Femoral morphology	Short stem (mm)	Standard stem (mm)	*p*-value
Dorr A	2.8 ± 1.0	1.9 ± 0.8	< 0.05
Dorr B	3.3 ± 0.9	1.9 ± 0.9	< 0.05
Dorr C	3.6 ± 2.0	2.1 ± 1.0	< 0.05

Discussion

Our findings revealed significantly greater intramedullary insertion freedom with short stems than with standard stems across all medullary shapes (Dorr A, B, and C). However, it is important to note that this study was conducted using preoperative planning simulations, and no clinical measurements were performed. Therefore, these results should be interpreted with caution when applied to real-world clinical settings. Moreover, this enhanced freedom was associated with an increased AFO, particularly when the stem was inserted in a flexed position. In recent years, techniques that emphasize surgical minimization, including anterior approaches that preserve bone and soft tissues, have garnered popularity. The femoral component is likely to be inserted in a flexed position because of the difficulty in elevating the proximal femur [20]. In the present study, we demonstrated that large intramedullary insertion freedom can be achieved with short stems that can be inserted in the flexion/extension position. A marked change in AFO was observed after the insertion of the stem in the flexion/extension position, and the AFO was larger than that of the standard stem. Although approximately 20% of short stems have been reported to be in varus alignment [21, 22], stem malalignment in the sagittal plane has not been reported.

Functional anteversion angle and AFO play critical roles in ensuring sufficient postoperative ROM [23]. If the AFO is reduced and the center of the femoral head shifts posteriorly, the flexion angle of the hip joint decreases, increasing the risk and severity of bony impingement [24]. This posterior shift may limit the patient's ability to achieve full hip flexion, thereby potentially affecting the overall functional outcomes and increasing the likelihood of postoperative complications [25]. These reports suggest that AFO is more important than stem anterior migration in determining the ROM and risk of bony impingement after THA. The AFO, which represents the anterior-posterior distance from the center of the femoral head, can be established by placing the short stem in a flexed orientation, irrespective of the underlying bone medullary shape. Even with the standard stem, in the case of a stovepipe-type medullary morphology, the AFO can be achieved this way. However, the risk of misalignment increases when a short stem is used in patients with wider medullary canals, such as those with a stovepipe morphology. The increased intramedullary insertion freedom associated with short stems may cause deviations from the preoperative plan, potentially affecting the postoperative ROM. As this study lacked clinical data, the generalizability of the findings remains limited, and further clinical validation is necessary to confirm these observations. In addition, if a short stem is inserted in the flexion/extension position in the femoral medulla of the stovepipe type, the risk of early loosening and subsidence of the stem and intraoperative femoral fractures may increase [26].

Our study has several limitations. First, the results were obtained using a computer simulation model, and no clinical data were included. Additionally, the simulation did not account for soft tissue factors that could influence stem placement and alignment during surgery. Furthermore, this study focused exclusively on idealized scenarios, and the outcomes may differ in cases involving complex deformities or unique patient-specific anatomical challenges. These limitations highlight the need for future clinical studies to validate our findings and assess the impact of short stem usage in diverse patient populations. Therefore, these results should be interpreted with caution and verified in future clinical studies. Soft-tissue-related factors were ignored in the simulation studies, as it was only possible to compare the two stem types through simulations. Owing to its retrospective nature, this study was susceptible to selection bias. Moreover, owing to the difficulty in identifying the center of the femoral head when severe deformation was present, we simulated cases in which the femur was minimally deformed. Future studies should validate these findings through clinical trials and explore the impact of short stems on long-term outcomes in diverse patient populations. Additionally, research focusing on intraoperative challenges and postoperative recovery related to short stems would provide valuable insights for optimizing surgical planning and techniques.

Conclusions

The use of short stems increases the degree of freedom for intramedullary stem insertion, potentially improving alignment in certain cases. However, this increased freedom also presents a risk of improper stem placement, particularly in patients with wider marrow morphologies, such as those with stovepipe-type femurs. Careful preoperative planning and precise surgical techniques are essential to mitigate these risks. Future studies should focus on validating these findings in clinical settings and exploring strategies to further optimize stem placement.

Abbreviations

3D	Three-dimensional
AFO	Anterior femoral offset
CT	Computed tomography
ROM	Range of motion
THA	Total hip arthroplasty

Acknowledgements

We would like to thank Editage for English language editing.

Author contributions

Conceptualization: TK; Methodology: TK; Formal analysis: MI, DI; Validation: DI; Data Curation: DI; Resources: MI; Visualization: YY, TI; Supervision: TK, SD; Project administration: TK, SD; Funding acquisition: TK; Writing - Original Draft: MI; Writing - Review & Editing: TK.

Funding

This work was not supported by any external funding.

Data availability

The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study adhered to the principles of the Declaration of Helsinki. The need for ethics approval was waived by the Medical Ethics Committee of Kanazawa University according to the "Ethical Guidelines for Medical and Health Research Involving Human Subjects" provided by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of Health, Labour and Welfare (MHLW) in Japan. Written informed consent was acquired from all participants. Confidentiality and anonymity were ensured, and participants were informed of their right to withdraw at any time.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Orthopedic Surgery, Graduate School of Medical Science, Kanazawa University, 13-1 Takaramachi, Kanazawa 920-8641, Ishikawa, Japan

Received: 14 July 2024 / Accepted: 17 February 2025

Published online: 24 February 2025

References

1. Zang J, Uchiyama K, Moriya M, Li Z, Fukushima K, Yamamoto T, et al. Long-term clinical and radiographic results of the cementless Spotorno stem in Japanese patients: a more than 15-year follow-up. J Orthop Surg (Hong Kong). 2018;26:2309499017750310.
2. Alpaugh K, Chiu YF, Zlotnicki JP, Bendich I, Valle AGD, Bostrom MPG, et al. Femoral component undersizing and alignment are risk factors for early periprosthetic femur fracture. J Arthroplasty. 2022;37:S604–10.
3. Kutzner KP, Freitag T, Donner S, Kovacevic MP, Bieger R. Outcome of extensive varus and valgus stem alignment in short-stem THA: clinical and radiological analysis using EBRA-FCA. Arch Orthop Trauma Surg. 2017;137:431–9.
4. Vaughan PD, Singh PJ, Teare R, Kucheria R, Singer GC. Femoral stem tip orientation and surgical approach in total hip arthroplasty. Hip Int. 2007;17:212–7.
5. Abe H, Sakai T, Takao M, Nishii T, Nakamura N, Sugano N. Difference in stem alignment between the direct anterior approach and the posterolateral approach in total hip arthroplasty. J Arthroplasty. 2015;30:1761–6.
6. Lettich T, Tierney MG, Parvizi J, Sharkey PF, Rothman RH. Primary total hip arthroplasty with an uncemented femoral component: two- to seven-year results. J Arthroplasty. 2007;22:43–6.
7. Horwood NJ, Nam D, Greco NJ, Lombardi AV Jr, Clohisy JC, Lawrie CM, et al. Reduced thigh pain with short femoral stem design following direct anterior primary total hip arthroplasty. Surg Technol Int. 2019;34:437–44.
8. Kutzner KP, Pfeil J. Individualized stem-positioning in calcar-guided short-stem total hip arthroplasty. J Vis Exp. 2018;(132):e56905.
9. Patel RM, Smith MC, Woodward CC, Stulberg SD. Stable fixation of short-stem femoral implants in patients 70 years and older. Clin Orthop Relat Res. 2012;470:442–9.
10. Yasunaga Y, Yamasaki T, Matsuo T, Yoshida T, Oshima S, Hori J, et al. Clinical and radiographical results of 179 thrust plate hip prostheses: 5–14 years follow-up study. Arch Orthop Trauma Surg. 2012;132:547–54.
11. Lombardi AV, Berend KR, Adams JB. A short stem solution: through small portals. Orthopedics. 2009;32:663.
12. Shoji T, Yasunaga Y, Yamasaki T, Mori R, Hamanishi M, Ochi M. Bony impingement depends on the bone morphology of the hip after total hip arthroplasty. Int Orthop. 2013;37:1897–903.

13. Dorr LD, Faugere MC, Mackel AM, Gruen TA, Bognar B, Malluche HH. Structural and cellular assessment of bone quality of proximal femur. Bone. 1993;14:231–42.
14. Shoji T, Yamasaki T, Izumi S, Murakami H, Mifuji K, Sawa M, et al. Factors affecting the potential for posterior bony impingement after total hip arthroplasty. Bone Joint J. 2017;99–B:1140–6.
15. Miki H, Kyo T, Sugano N. Anatomical hip range of motion after implantation during total hip arthroplasty with a large change in pelvic inclination. J Arthroplasty. 2012;27:1641–e501.
16. Kingsley PC, Olmsted KL. A study to determine the angle of anteversion of the neck of the femur. J Bone Joint Surg Am. 1948;30:745–51.
17. Sugano N, Noble PC, Kamaric E, Salama JK, Ochi T, Tullos HS. The morphology of the femur in developmental dysplasia of the hip. J Bone Joint Surg Br. 1998;80:711–9.
18. Feyen H, Shimmin AJ. Is the length of the femoral component important in primary total hip replacement? Bone Joint J. 2014;96–B:442–8.
19. Yoshitani J, Kabata T, Kajino Y, Takagi T, Ohmori T, Ueno T, et al. The effect of flexion alignment in total hip arthroplasty with a cementless tapered-wedge femoral stem. Eur J Orthop Surg Traumatol. 2018;28:1625–32.
20. Min BW, Song KS, Bae KC, Cho CH, Kang CH, Kim SY. The effect of stem alignment on results of total hip arthroplasty with a cementless tapered-wedge femoral component. J Arthroplasty. 2008;23:418–23.
21. Nishioka ST, Andrews SN, Mathews K, Nakasone CK. Varus malalignment of short femoral stem not associated with post-hip arthroplasty fracture. Arch Orthop Trauma Surg. 2022;142:3533–8.
22. Molli RG, Lombardi AV Jr, Berend KR, Adams JB, Sneller MA. A short tapered stem reduces intraoperative complications in primary total hip arthroplasty. Clin Orthop Relat Res. 2012;470:450–61.
23. Worlicek M, Weber M, Craiovan B, Wörner M, Völlner F, Springorum HR, et al. Native femoral anteversion should not be used as reference in cementless total hip arthroplasty with a straight, tapered stem: a retrospective clinical study. BMC Musculoskelet Disord. 2016;17:399.
24. Yoshitani J, Kabata T, Kajino Y, Ueno T, Ueoka K, Yamamuro Y, et al. Anatomic stem inserted according to native anteversion could reproduce the native anterior distance of the femoral head and decrease bony impingement in total hip arthroplasty. Int Orthop. 2020;44:245–51.
25. Hirata M, Nakashima Y, Hara D, Kanazawa M, Kohno Y, Yoshimoto K, et al. Optimal anterior femoral offset for functional range of motion in total hip arthroplasty—a computer simulation study. Int Orthop. 2015;39:645–51.
26. Wade FA, Parvizi J, Sharkey PF, Purtill JJ, Hozack WJ. Femoral perforation complicating contemporary uncemented hip arthroplasty. J Arthroplasty. 2006;21:452–5.

Publisher's note