Adjustment of stem anteversion using tapered cone stem in total hip arthroplasty

implant survival, simulation of impingement reduction, and patient-reported benefits

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Aims
The aim of this study was to evaluate the suitability of the tapered cone stem in total hip arthroplasty (THA) in patients with excessive femoral anteversion and after femoral osteotomy.

Methods
We included patients who underwent THA using Wagner Cone due to proximal femur anatomical abnormalities between August 2014 and January 2019 at a single institution. We investigated implant survival time using the endpoint of dislocation and revision, and compared the prevalence of prosthetic impingements between the Wagner Cone, a tapered cone stem, and the Taperloc, a tapered wedge stem, through simulation. We also collected Oxford Hip Score (OHS), visual analogue scale (VAS) satisfaction, and VAS pain by postal survey in August 2023 and explored variables associated with those scores.

Results
Of the 58 patients (62 hips), two (two hips) presented with dislocation or reoperation, and Kaplan-Meier analysis indicated a five-year survival rate of 96.7% (95% CI 92.4 to 100). Mean stem anteversion was 35.2° (SD 18.2°) for the Taperloc stem and 29.8° (SD 7.9°) for the Wagner Cone stem; mean reduction from Taperloc to Wagner Cone was 5.4° (SD 18.8°). Overall, 55 hips (52 patients) were simulated, and the prevalence of prosthetic impingement was lower for the Wagner Cone (5.5%, 3/55) compared with the Taperloc (20.0%, 11/55) stem, with an odds ratio of 0.20 ($p = 0.038$). Among the 33 respondents to the postal survey (36 hips), the mean scores were VAS pain 10.9, VAS satisfaction 86.9, and OHS 44.7. A multivariable analysis revealed that reduction of stem anteversion from Taperloc to Wagner Cone was more favourable for VAS pain ($p = 0.029$) and VAS satisfaction ($p = 0.002$).

Conclusion
The mid-term survival rate for THA using the Wagner Cone stem was high, which may be supported by a reduction in prosthetic impingement. The reduction in excessive stem anteversion by using a tapered cone stem was associated with reduced pain and increased patient satisfaction.

Take home message
- Tapered cone stems can increase within-target implantation and reduce prosthetic impingement.
- Adjustment of stem anteversion can improve patients' pain and satisfaction.

Introduction
Prosthesis impingement is the leading cause of dislocation during total hip arthroplasty (THA).[1] Although recent technological advancements have improved cup placement accuracy,

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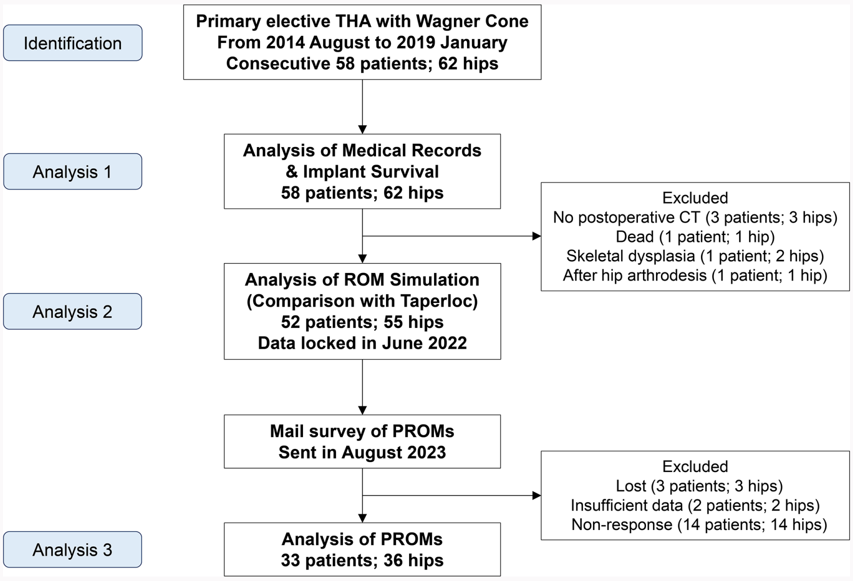

Fig. 1
Flow diagram of the study. PROMs, patient-reported outcome measures; ROM, range of motion; THA, total hip arthroplasty.

anomalies in stem angle can still lead to prosthetic impingement.[2] Notably, deviations in femoral head anteversion are frequent, and cause greater femoral anteversion in patients with developmental dysplasia of the hip (DDH),[3,4] which is regarded as the primary cause of osteoarthritis (OA) among specific populations, such as Japanese patients.[5]

The Wagner Cone prosthesis (Zimmer Biomet, USA) is a tapered cone stem used in THA, and is especially beneficial in patients with an abnormal proximal femoral anatomy.[6] The unique design not only allows for adaptability in surgeries, accommodating varying femoral geometries, but also enables adjustment of stem anteversion. However, there is limited research on how well this stem enables correct anteversion, especially in unique bone morphologies, such as Asian populations, or after femoral osteotomy.

We therefore aimed to evaluate the suitability of the Wagner Cone in THA in patients with unique bone morphologies. Our research questions were as follows: 1) What is the five-year survival rate after THA using a Wagner Cone with dislocation and revisions as endpoints? 2) Did the Wagner Cone increase the rate of within-target installation and reduce the incidence of prosthetic impingement compared to a morphology-based stem?; and 3) Was adjustment for stem anteversion associated with mid-term patient-reported outcome measures (PROMs)? We hypothesized that the use of the Wagner Cone would enhance the accuracy of achieving the target implant placement angle, potentially reducing the risk of prosthetic impingement and dislocation in Asian patients undergoing THA with abnormal femoral neck bone morphology, thereby promoting favourable mid-term implant survival and PROMs.

Methods

Design and setting

This case series was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.[7] After obtaining approval from our local institutional review board (approval number 21142–00), we retrospectively reviewed the data of patients who underwent THA for symptomatic osteoarthritis between August 2014 and January 2019 at our university hospital (Kyushu University, Japan), a period in which postoperative CT was intensively performed as part of routine care for the early detection of implant alignment issues. The sample size was not designed to support the statistical power based on hypothesis testing. We conducted three analyses using a single dataset (Analyses 1 to 3).

Participants

We identified 58 consecutive Asian patients (62 hips) who underwent primary cementless elective (not traumatic) THA using a Wagner Cone prosthesis and assessed them for eligibility (Figure 1), all of whom were included to evaluate implant survival time (Analysis 1). This represented 6.4% of the patients (58 of 909) undergoing primary THA at our hospital during the study period; a small percentage because the tapered cone stem is reserved for patients with proximal femur anatomical abnormalities identified from the evaluation of preoperative CT.

Subsequently, patients were selected for CT simulation. We excluded patients who did not undergo postoperative CT, and those in whom we could not measure stem anteversion because it was impossible to place a virtual Taperloc stem on the preoperative CT, such as those with multiple trauma, post-hip fusion, or pseudoarticular or bony system diseases. After excluding these patients, we analyzed data from 52 patients (55 hips) for CT simulation analysis (Analysis 2).

In August 2023, we conducted a postal survey of the 52 patients and analyzed the PROMs of respondents from 33 patients (36 hips). The survey response rate was 63.5% (Analysis 3).

Surgical technique

All patients included in this study underwent manually instrumented THA using a Wagner Cone prostheses in the

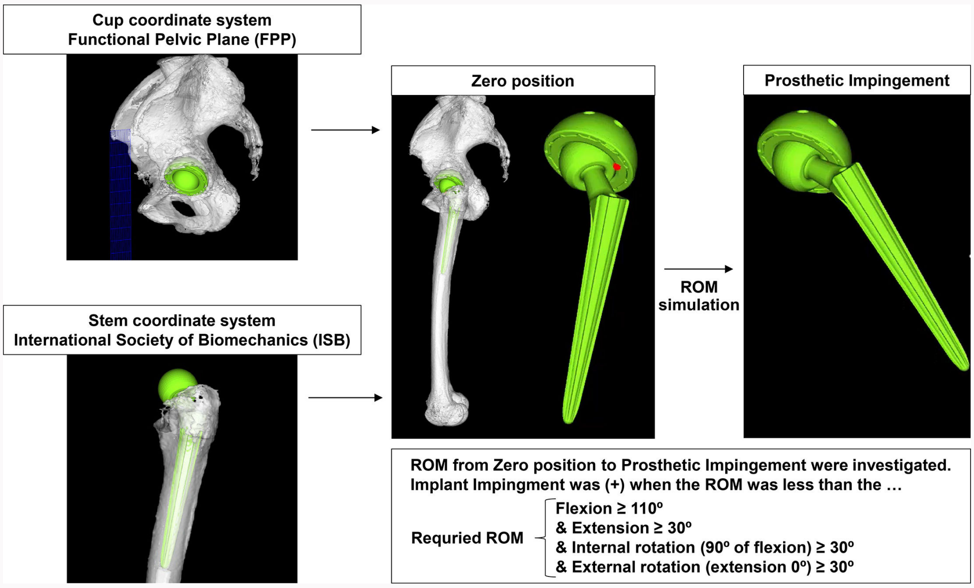

Fig. 2

CT-based simulation software (ZedHip; Lexi Co, Ltd, Japan) was used to semi-automatically create virtual 3D bone models, and perform virtual range of motion (ROM) simulation and the probability of prosthetic impingement. The functional pelvic plane (FPP) was used for coordinates of the pelvis, which were defined as follows: 1) the axial reference was the anterior pelvic surface through the right and left superior anterior iliac spines and pubic tuberosity; 2) the anterior-posterior axis was tilted according to the inclination of the anterior pelvic surface when the patient was lying supine on the CT table. The femoral coordinate system was defined, as per the International Society of Biomechanics,[10] as being the centre of the femoral head, knee centre, and both femoral condyles. The alignment of the cup and stem and combined anteversion were measured based on the coordinate systems.

same group by six senior surgeons (SH, GM, YN, SI, MF, JF). All surgeries were performed using the posterolateral approach. During the time period under review, the Wagner Cone was selected to reduce stem version for excessive anteversion of the bone morphology, to increase stem version in cases of small anteversion of the bone morphology, and for cases after femoral osteotomy or for other reasons. A total of 58 patients (62 hips; mean age 60.2 years (SD 11)) underwent THA with the Wagner Cone stem; one patient underwent a combined transverse subtrochanteric shortening osteotomy. A total of 24 hips (39%) had a history of previous femoral surgery using various techniques (Table I).

The target angle of stem anteversion was 30° in all cases, determined using a goniometer, as the angle between the axis of the lower leg and the axis of the trial stem by flexing the knee and placing the tibia vertically. The cups were installed using guide rods with a target of 40° inclination and 20° anteversion, according to the stem anteversion so that the combined anteversion (CA), the sum of cup anteversion and stem anteversion, was 50° (SD 10°).[2]

Cementless acetabular cups were used in all procedures, including the G7 cup (Zimmer Biomet) in 43 hips, the Continuum cup (Zimmer Biomet) in 18 hips, and the Trabecular Metal Acetabular System (Zimmer Biomet) in one hip. The head size was 32 mm in 59 hips and 28 mm in three hips, with zirconia-toughened alumina ceramic heads in 60 hips and cobalt-chromium heads in two hips. Cross-linked polyethylene was used in all hips, consisting of an elevated liner in 33 hips and a neutral liner in 29 hips with a single mobility construct.

Outcomes

We investigated implant survival time using the endpoint of complications that required reoperation. We also investigated the incidence of dislocation, rate of infection, incidence of femoral cracks that required wiring, and amount of stem subsidence by reviewing the medical records from 16 April 2024. Stem subsidence was measured on radiography as the distance from a line drawn perpendicular to the femoral axis at the superior aspect of the greater trochanter (A) to the most proximal part of the stem (B) according to Sakamoto et al.[8] We collected range of motion (ROM) data for hip flexion and abduction from medical records at the final examination day.

CT-based simulation software (ZedHip; Lexi Co, Ltd, Japan) was used to semi-automatically create virtual 3D bone models and perform virtual ROM simulation (Figure 2).[9] This software includes an implant database with 3D computer-aided design (CAD) models provided by the manufacturer, and can define the maximum ROM without prosthetic impingement.[9] All CT images (Aquilion; Toshiba, Japan) were obtained with the patients in a supine position, at 1 mm intervals from the anterior superior iliac spine to the knee, including the distal femoral condyles.[9] The same type and sizes of the Wagner Cone stem and cup were superimposed in the actual implant placement position.[9] All cases were simulated using a flat liner to eliminate the effects of the liner type and the position of the elevated wall. We used the following required ROM for activities of daily living: flexion > 110°, internal rotation (IR) > 30° at 90° flexion, extension > 30°, and external rotation (ER) > 30.[9]

As a simulation control, Taperloc (Taperloc Complete, Zimmer Biomet, USA), a tapered wedge stem, was virtually installed and used at our institution as the first-line stem in primary THA during the study period. Preoperative CT was used for the simulation, and the CAD of the Taperloc was inserted in the most congruent position with the medullary cavity at the centre level of the lesser trochanter according

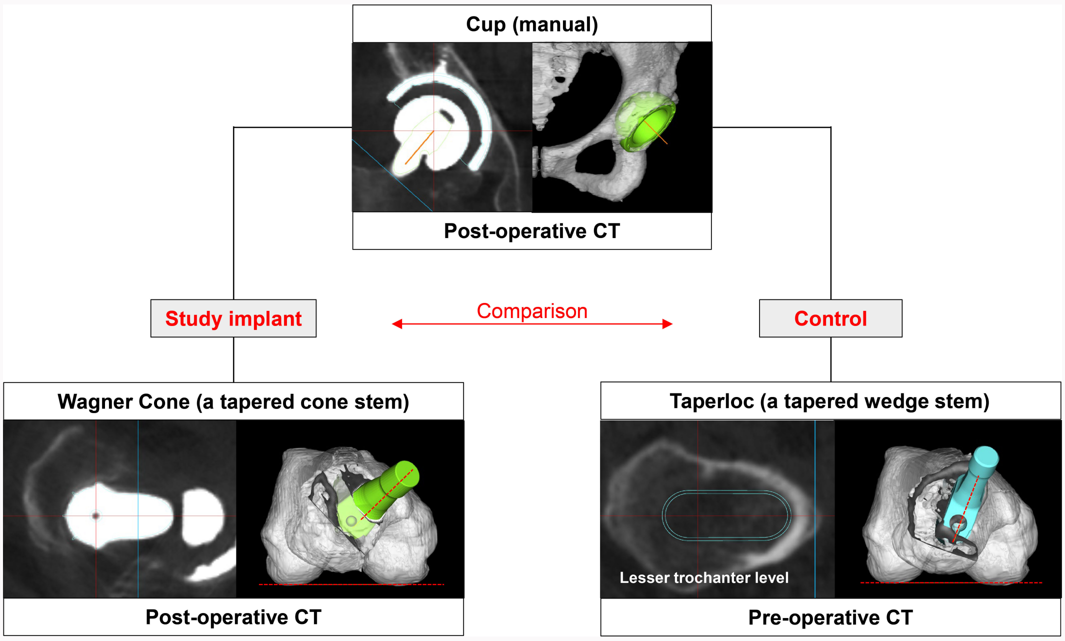

Fig. 3
As a control in the simulation, the Taperloc (Taperloc Complete; Zimmer Biomet, USA) was virtually installed in the most congruent position, with the medullary cavity at the centre level of the lesser trochanter, and ensuring that the entire 3D computer-aided design (CAD) models of the stem fitted within the medullary cavity according to the bone morphology.

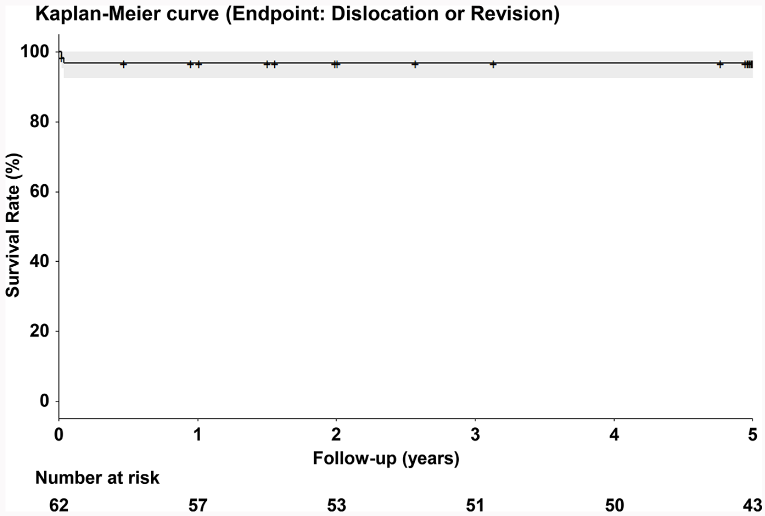

Fig. 4
Kaplan-Meier survival curve and 95% CI. The endpoint was dislocation or revision. Patients lost to follow-up (including death) were censored at the date of last contact.

to the bone morphology (Figure 3).[11] All simulation results were completed, and the data were locked by June 2022. The two authors additionally simulated the best-case scenario for control by permitting the adjustment of the stem anteversion within a range that did not penetrate the cortex, rather than strictly following the bone morphology.

PROMs were collected through a cross-sectional postal survey conducted in August 2023. The Oxford Hip Score (OHS),[12,13] visual analogue scale (VAS) satisfaction,[14] and VAS pain[15] were obtained. The OHS is a disease-specific quality of life measure for hip osteoarthritis that has been validated in Japanese,[16] ranging from 0 to 48, with higher scores indicating better pain and function outcomes. The VAS for satisfaction ranges from 0 to 100, where 0 is 'not at all satisfied with the surgery' and 100 is 'very satisfied with the surgery'. For VAS pain, the question was, 'How severe is your hip pain?'. This was converted into a score between 0 and 100, with higher scores indicating greater pain.

We investigated the associations between PROMs and stem anteversion change from the Taperloc to the Wagner Cone, including seven other variables (age at survey, follow-up year, sex, BMI, history of femoral osteotomy, complications (dislocation, revision, femoral crack, surgical site infection,

Table I. Patient demographic data.

Variable	Analysis 1 (Medical records + implant survival)	Analysis 2 (ROM simulation)	Analysis 3 (PROMs postal survey)
Total hips (patients)	62 (58)	55 (52)	36 (33)
Mean age at survey, yrs (SD)	60.2 (11.0)	60.2 (10.2)	61.1 (9.7)
Mean follow-up from THA to last examination, yrs (range)	4.6 (0.5 to 9.0)		5.6 (4.6 to 9.0)
Mean follow-up from THA to last data collection, yrs (range)	6.4 (5.3 to 9.7)		5.6 (4.6 to 9.0)
Sex, n (%)			
Male	18 (29)	15 (27)	11 (31)
Female	44 (71)	40 (73)	25 (69)
Mean BMI, kg/m^2 (SD)	24.0 (3.9)	23.7 (4.0)	23.8 (3.9)
Surgical side, n (%)			
Right	30 (48)	28 (51)	17 (47)
Left	32 (52)	27 (49)	19 (53)
Diagnosis, n (%)			
OA	49 (79)	45 (82)	29 (81)
ONFH	10 (16)	10 (18)	7 (19)
After hip arthrodesis	1 (2)		
Skeletal dysplasia	2 (3)		
Crowe classification[18], n (%)			
I	44 (71)	38 (69)	25 (69)
II	13 (21)	12 (22)	9 (25)
III	3 (5)	3 (5)	2 (6)
IV	2 (3)	2 (4)	
Previous femoral surgery, n (%)			
None	38 (61)	33 (60)	20 (56)
Varus osteotomy	10 (16)	10 (18)	6 (17)
Valgus osteotomy	3 (5)	2 (4)	2 (6)
Anterior rotational osteotomy	6 (10)	6 (11)	5 (14)
Unclassifiable	4 (7)	4 (7)	3 (8)
After hip arthrodesis	1 (2)		
Measurements using preoperative CT with Taperloc stem			
Mean stem anteversion, ° (SD)		35.2 (18.2)	36.5 (18.7)
Mean combined anteversion, ° (SD)		56.2 (16.5)	58.5 (16.9)
Within-target rates of combined anteversion, n (%)		22 (40.0)	12 (33.3)
Prosthetic impingement, n (%)		11 (20.0)	10 (27.8)

OA, osteoarthritis; ONFH, osteonecrosis of the femoral head; PROMs, patient-reported outcome measures; ROM, range of motion; THA, total hip arthroplasty.

and simulation-based prosthetic impingement), and stem subsidence).

Statistical analysis

Implant survival was calculated as the endpoint of cumulative probability of dislocation or revision estimated using the Kaplan-Meier method; the CI was set at 95%. We performed an *F* test to compare the variance in stem anteversion between the two scenarios. To compare the probability of achieving the target CA zone and the probability of prosthetic impingement occurring in each of the two scenarios, we used conditional logistic regression analysis to calculate odds ratios (ORs) and test for significant differences by considering that the two scenarios originated from the same patients. Finally, we conducted multivariable regression analysis with each PROM as the dependent variable and the other variables

Table II. Variables from electronic medical records (n = 62).*

Variable	Value
Femoral cracks, n (%)	3 (4.8)
Found intraoperatively	2 (3.2)
Found postoperatively	1 (1.6)
Dislocation, n (%)	1 (1.6)
Superficial incisional-SSI, n (%)	1 (1.6)
Deep incisional-SSI, n (%)	0 (0.0)
Revisions, n (%)	1 (1.6)
Final stem subsidence, mm, mean (SD)	3.1 (4.0)
Mean ROM for hip flexion at final examination, ° (SD)	101.5 (16.9)
Mean ROM for hip abduction at final examination, ° (SD)	29.6 (2.7)
Five-year implant survival rate, % (95% CI) (endpoint: dislocation or revision)	96.7 (92.4 to 100; 43 hips at risk)

*All data were obtained by accessing electronic medical records up to medical records until 16 April 2024.
ROM, range of motion; SSI, surgical site infection.

Table III. Simulation comparing the Wagner Cone and Taperloc stem replacement (n = 55).

Variable	Value
Mean cup inclination, ° (SD)	40.6 (7.5)
Mean cup anteversion, ° (SD)	21.0 (7.1)
Mean Wagner Cone stem anteversion, ° (SD)	29.8 (7.9)
Mean combined anteversion, ° (SD)*	50.8 (9.4)
Mean stem anteversion replacing with Taperloc stem, ° (SD)	35.2 (18.2)
Mean reduction of stem anteversion, ° (SD) (from Taperloc to Wagner Cone)	5.4 (18.8)
Within-target rates of combined anteversion, n (%)	42 (76.4)
(control: replacing with Taperloc stem)	22 (40.0)
Crude odds ratio (95% CI)†	4.77 (2.10 to 10.8, p < 0.001)
Adjusted odds ratio (95% CI)†	3.50 (1.60 to 7.68, p = 0.002)
Prosthetic impingement, n (%)	3 (5.5)
(control: replacing with Taperloc stem)	11 (20.0)
Crude odds ratio (95% CI)†	0.23 (0.06 to 0.89, p = 0.033)
Adjusted odds ratio (95% CI)†	0.20 (0.04 to 0.91, p = 0.038)

*Combined anteversion = cup anteversion + stem anteversion.
†Taperloc used as reference.

as independent variables. The variables that had an effect were selected in the backward and forward stepwise selection processes to minimize the Akaike information criterion. Missing PROMs data were difficult to evaluate because of the small sample size; only complete respondents were analyzed under the assumption that the data were missing completely at random.[17] All analyses were conducted using R version 4.3.1 (R Foundation for Statistical Computing, Austria) and Rstudio (version 2023.06.1; R Studio, USA). Statistical significance was considered to be p < 0.05.

Results

Dislocation occurred in one patient on postoperative day 13 when the patient stretched on the bed during ongoing postoperative inpatient rehabilitation. In two hips, femoral cracks were found intraoperatively, and in one case, a periprosthetic fracture was identified on postoperative day 7; the patient subsequently underwent revision surgery for additional fixation with wiring (Table II). These three patients with fractures had not undergone a previous femoral osteotomy. The Kaplan-Meier analysis indicated five-year survival rates of 98.3% (95% CI 95.1 to 100; 43 hips at risk) for dislocation as the endpoint (Supplementary Figure a), 98.4% (95% CI 95.3 to 100; 43 hips at risk) for revision (fracture fixation) as the endpoint (Supplementary Figure b), and 96.7% (95% CI 92.4 to 100; 43 hips at risk) for dislocation or revision (fracture fixation) as the endpoint (Figure 4). At the final follow-up examination, the mean range of motion was 101.5° (SD 16.9°) for hip flexion and 29.6° (SD 2.7°) for hip abduction.

Overall, 55 hips (52 patients) were analyzed using CT simulation. The SD of the Wagner Cone stem anteversion was 7.9°, whereas for the Taperloc stem it was 18.2°, for which the variances were significantly smaller in the Wagner Cone anteversion (p < 0.001, *F* test, Figure 5). The mean stem anteversion was 35.2° for the Taperloc stem and 29.8° for the Wagner Cone stem; mean reduction from Taperloc to Wagner Cone was 5.4° (SD 18.8°). The target zone achievement of CA was higher in the Wagner Cone (76.4%, 42 of 55) compared with the Taperloc (40.0%, 22 of 55) stem by adjusted OR of 3.50 (95% CI 1.60 to 7.68; p = 0.002, conditional logistic regression analysis). In the subsequent ROM simulation, the probability of prosthetic impingement was lower for the Wagner Cone (5.5%, three of 55) compared with Taperloc (20.0%, 11 of 55) by adjusted OR of 0.20 (95% CI 0.04 to 0.91, p = 0.038, conditional logistic regression analysis; Table III). In the best-case scenario for Taperloc, where the anteversion of the stem was adjusted within the range that did not penetrate the cortex rather than strictly following the bone morphology, implant impingement did not occur in any of the Taperloc simulations.

The three hips with Wagner Cones that had impingement simulation had no prior femoral osteotomies. In one case of actual dislocation, the CA was installed within the target and the simulation did not cause impingement; however, the cup inclination was far outside the target zone (Figure 6). One patient, who did not undergo a previous femoral osteotomy, had a previous fixation due to a femoral shaft fracture.

Among the survey respondents, 36 hips (33 patients) after the simulation had the following scores: VAS pain mean 10.9 (SD 20.1, Supplementary Figure c); VAS satisfaction 86.9 (SD 20.4, Supplementary Figure d); OHS 44.7 (SD 5.1, Supplementary Figure e). Multivariable analysis revealed that a history of femoral osteotomy and changes in stem anteversion were associated with PROMs (Table IV), with no history being

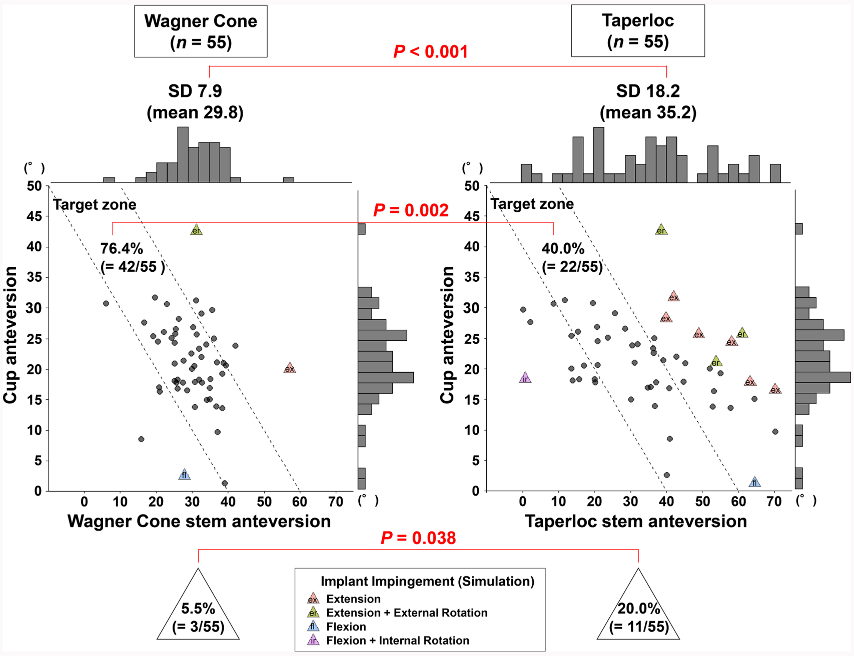

Fig. 5

The results of CT simulation comparing the Wagner Cone and Taperloc stems (both Zimmer Biomet, USA). The cup positioning angle used in the simulation was the common result of superimposing on the postoperative CT.

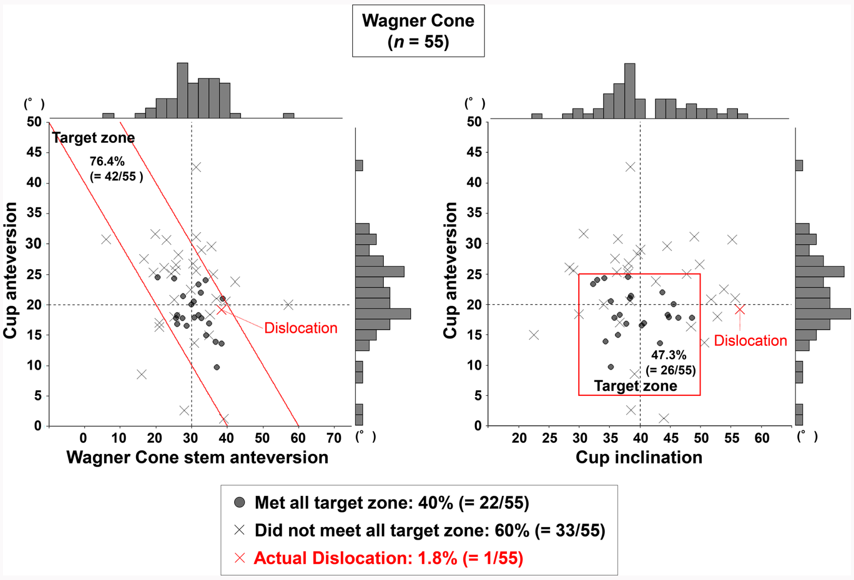

Fig. 6

The angle of placement of the cup was measured, superimposed upon the postoperative CT image. Dislocations show the results that occurred in clinical practice.

more favourable for VAS pain (p = 0.012), VAS satisfaction (p = 0.043), and OHS (p = 0.020). The reduction of stem anteversion from Taperloc to Wagner Cone was more favourable for VAS pain (p = 0.029) and VAS satisfaction (p = 0.002).

Discussion

The five-year survival rate after THA using Wagner Cone was 96.7%, and the prosthesis was associated with an increase in the rate of within-target installation and reduction in the incidence of prosthetic impingement compared to the morphology-based stem. In our study, adjustment for stem anteversion was associated with improved mid-term PROMs; specifically, the use of a tapered cone stem to reduce excessive anteversion has resulted in reduced pain and increased patient satisfaction.

High implant survival rates with the Wagner Cone have been demonstrated. Consistent with our findings, Kayani et al[19] reported ten-year survival of 95.8%; Gholson et al[20] reported 3.2-year survival of 98.7%; Lawson et al[21] reported five-year survival of 96.8% and 13-year survival of 96.8%; and Ors et al[22] reported ten-year survival of 96.9% for THA in patients with Crowe IV[18] DDH using the Wagner

Table IV. Multivariable regression analyses of the patient-reported outcome measures.

Outcome measure	β (95% CI)	p-value
VAS pain (n = 35, mean score 10.9, SD 20.1)		
BMI, kg/m^2	-1.04 (-2.1 to 0.04)	0.059
Previous femoral osteotomy (ref: no history)	12.8 (4.8 to 20.7)	0.003
Reduction of stem anteversion with Wagner Cone (ref: Taperloc)	-0.5 (-0.7 to -0.24)	< 0.001
Male (ref: female)	8.4 (-0.9 to 17.7)	0.076
Stem subsidence (per 1 mm)	0.3 (-0.1 to 0.7)	0.170
VAS satisfaction (n = 36, mean score 86.9, SD 20.4)		
Male (ref: female)	-14.6 (-27.7 to -1.5)	0.030
Previous femoral osteotomy (ref: no history)	-12.8 (-24.4 to -1.3)	0.030
Reduction of stem anteversion with Wagner Cone (ref: Taperloc)	0.6 (0.2 to 0.9)	0.002
Oxford Hip Score (n = 36, mean score 44.7, SD 5.1)		
Previous femoral osteotomy (ref: no history)	-3.8 (-7.0 to -0.7)	0.018
Reduction of stem anteversion with Wagner Cone (ref: Taperloc)	0.1 (-0.0003 to 0.2)	0.051

PROMs, patient-reported outcome measures; VAS, visual analogue scale.

Cone. Although a longer follow-up period is necessary, early postoperative complications are infrequent, suggesting promising long-term outcomes.

Our simulation showed that using a tapered cone stem to adjust stem anteversion increases the accuracy of implant placement and reduces prosthetic impingement. When using tapered wedge stems to prevent impingement, the implants had to be positioned in a way that did not follow the bone morphology in 20% (11 of 55) of our participants. Patients with DDH have significantly greater femoral neck anteversion angles, with more variability than normal.[3] One cadaver study in 2003 reported differences in morphological femoral anteversion in Asian populations compared to Caucasian patients.[23] These findings underscore the need for careful adjustment of stem anteversion to prevent impingement, particularly in Asian patients, and tapered cone stems provide a valuable option.

Previous studies highlight the varied outcomes of THA after femoral osteotomy. Ohishi et al[24] reported a 12.5% fracture rate with press-fit stem intertrochanteric varus osteotomy; in our study, by contrast, proactive wiring to prevent fractures resulted in no occurrences of such fractures following osteotomy with the use of the Wagner Cone. Osawa et al[25] reported that Harris Hip Scores (HHSs)[26] in patients with primary THA for osteonecrosis of femoral head (ONFH) were poorer in those who had previous trochanteric rotational osteotomy versus those who did not. THA after anterior rotational osteotomy provides HHS outcomes comparable to those of THA without antecedent surgery for ONFH.[27] In our study, patients without a previous femoral osteotomy had higher scores on the patient-centred assessment. The overall dissatisfaction in some patients suggests that factors other than fractures need to be explored, as evidence for THA after femoral osteotomy remains limited.[28]

To the best of our knowledge, this is the first study to report the association between stem adjustment and PROMs. Our findings extend previous knowledge by demonstrating that identifying abnormal femoral anteversion cannot only assist in adjusting stem anteversion to reduce the risk of dislocation after THA, but also contribute to reduced patient pain and increased satisfaction.[2,4,29] Esbjörnsson et al[30] reported that a change in hip rotation during walking gait analysis was associated with a change in postoperative femoral neck anteversion in the same direction after THA. Excessive anteversion of the stem may, therefore, lead to an in-toeing gait related to walking difficulty; therefore, adjusting the anteversion angle is required for patients with abnormal femoral anteversion to achieve natural gait.

Our study has several limitations. Although we conducted multiple analyses, the study is essentially a case series with a low level of evidence. The simulation controls using postoperative data and retrospective analyses restricted our ability to establish causality. Due to the limitation posed by the potential for arbitrary installation angles of the Taperloc control stems, we conducted a mail survey of PROMs after finalizing the simulation data to address this issue. The anthropometric simulation model, while reflecting prosthetic impingement, did not account for bone impingement. The position of the elevated liner is an important factor in prosthetic impingement;[31] however, all cases in our study were simulated as flat liners because the actual orientation of the elevated liner installation could not be measured retrospectively. PROMs data were also derived from an uneven follow-up cross-sectional postoperative survey, with a small sample size and a response rate of 63.5%. Moreover, we could not consider the preoperative status; therefore, the preoperative status of patients with previous femoral osteotomy could be lower than that of patients without previous femoral osteotomy. Despite these limitations, the strength of this study lies in its multidimensional evaluation of clinically critical complications, imaging, simulation, and patient-centred outcomes.

In summary, the mid-term survival rate for THA using Wagner Cones was high, which may be supported by a reduction in prosthetic impingement. The reduction in excessive stem anteversion by using a tapered cone stem was associated with reduced pain and increased patient satisfaction.

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Supplementary material

Figures displaying Kaplan-Meier survival curves, and the association between reduction of stem anteversion from Taperloc to Wagner Cone and various patient-reported outcome measures.

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Data sharing

The datasets generated and analyzed in the current study are not publicly available due to data protection regulations. Access to data is limited to the researchers who have obtained permission for data processing. Further inquiries can be made to the corresponding author.

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Ethical review statement

Each author certifies that his institution approved the human protocol for this investigation and that all investigation was conducted in conformity with ethical principles of research. Ethical approval for this study was obtained from the Graduate School of Medical Sciences, Kyushu University (approval number 21142–00).

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