Original Article
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Modular and Non-modular Conical Tapered Stems in Total Hip Arthroplasty for Crowe III and IV Hip Dysplasia

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Background: Conical stems are effective in total hip arthroplasty for high-degree dysplasia, but no comparative studies about modular and non-modular versions are available. By comparing 3 conical stems in 3-dimensional (3D) computed tomography (CT)-based simulations in Crowe III and IV dysplasia, the study sought to assess the rate of implants allowing correct biomechanical reconstruction and the correlations between the 3 stem reconstructions and native hip morphology.

Methods: Using a 3D CT-based simulation, 3 different conical stems (single-taper, modular neck, and proximal junction modularity) were implanted in the same high-degree dysplastic hips. Proximal biomechanical restorations (femoral fitting, combined anteversion, offset reconstruction, leg lengthening, and tilt) were compared, and correlations with native anatomy were assessed. After a power analysis, 61 hips in 55 patients were included, with a mean age at CT of 56.26 ± 10.71 years: 41 hips (67.21%) were classified as Crowe III and 20 (32.79%) as Crowe IV.

Results: The rate of global acceptability (matching all 6 reconstructive parameters) was similar between the 3 stems: W, 52.5%; A, 47.5%; and M, 55.7% ($p = 0.66$). No single stem demonstrated superior performance in any reconstructive parameter ($p > 0.05$). No specific native anatomical features favored one stem design over another; the primary predictors for each femoral reconstruction were native center of rotation height and cup medialization. Native femoral anteversion had no impact on the reconstruction.

Conclusions: Similar proximal biomechanical reconstructions were provided by modular and non-modular stems: modular stems should be used with caution even in high-grade dysplastic hips, but may be useful in high offset anatomies.

Keywords: *Hip, Total hip arthroplasty, Osteoarthritis, Developmental dysplasia*

The choice of femoral component for total hip arthroplasty (THA) in developmental dysplasia of the hip is still debated.[1)] While cemented stems are viable solutions to address small femurs and provide some version adjustment, cementless stems are generally preferred, especially in younger patients.[1,2)] Many different types of cementless stems have been proposed for low-degree dysplasia.[3)] However, in high-riding dysplasia, cementless solutions are limited, and many authors have suggested conical tapered implants.[1-8)]

These implants offer reliable diaphyseal fixation, effectively bypassing the proximal-distal mismatch and addressing torsional anomalies.[1-8)] Conical tapered stems may come in modular and non-modular options.[1,4-6)] Modular stems may provide further version adjustment and may fine-tune femoral offset and leg length, but at the price of possible modular junction failure.[5,6)] Non-modular stems have more limited reconstructive options (usually

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designed for complex and dysplastic cases) with no risk of modular interface failure.[7]

Both the modular and non-modular conical tapered implants achieved solid outcomes in non-comparative studies.[1] Di Martino et al.[3] noticed similar long-term survival rates for stem focused endpoints (dislocations and stem aseptic loosening) in a registry study. However, non-modular conical stems demonstrated the highest risk of implant failure among anatomic, tapered and conical designs, with single-taper or dual-taper options.[3] Liu et al.[8] compared the femoral fitting of off-the-shelf modular (S-Rom, DePuy) and non-modular (Wagner Cone, Zimmer) implants in 24 computed tomography (CT)-based simulations for Crowe IV hips: the authors concluded that modular implants provided some fitting advantages over non-modular ones, even though both stems failed to fit some femurs.

However, to date, no comparative evaluation of the reconstruction of proximal biomechanical parameters in high-riding dysplasia with modular and non-modular conical tapered stems is available. Thus, using a 3-dimensional (3D) CT-based preoperative planning software, the implantation of 3 cementless conical tapered stems in a series of Crowe III and IV hips was simulated for every hip. The selected stems were a single-taper conical tapered stem, a modular neck conical tapered implant, and a conical tapered stem with proximal modular junction. We sought to determine (1) the rate of implants allowing correct biomechanical reconstruction (femoral fitting, combined anteversion, offset reconstruction, leg lengthening, coronal, and sagittal tilt) and (2) the correlations between the reconstructions provided by each stem design and native hip morphology. We hypothesized that modular stems could fit as many dysplastic femurs as non-modular implants and could not improve the proximal biomechanical reconstruction compared to non-modular stems, particularly in terms of combined anteversion, offset reconstruction, and leg overlengthening.

METHODS

This study was approved by the Institutional Board Review of IRCCS Istituto Ortopedico Rizzoli (IRB No. CE-AVEC 29/2021/Oss/IOR, February 1, 2021). Informed consent was obtained from all patients.

This is a simulation study performed on previously acquired CT scans of native dysplastic hips classified as Crowe III or IV, identified through a database screening at a tertiary referral center specializing in complex hip surgeries.[9] These CT scans were performed for preoperative planning from 2000 to 2018. The inclusion criteria required CT scans that extended from the lumbar vertebral tract to the tibial plateaus with native dysplastic hips graded III or IV according to Crowe. Other congenital pathologies, low-grade dysplasia, short CT scans, and replaced hips were excluded. A priori power analysis demonstrated that at least 60 patients were required. A total of 62 hips meeting the inclusion criteria were randomly selected from 5,219 CTs, with the goal of slightly surpassing the minimum required enrollment number.

Planning Software, Implants and Simulation Technique

A 3D CT-based preoperative planning software, HipOp-Plan, was adopted to assess the native anatomy and simulate implant positioning. HipOp-Plan (Rizzoli Orthopaedic Institute) is a software application for hip arthroplasty surgical planning based on CT DICOM images.[10,11] The user-friendly workflow, with 4 different layout views, allows interactive positioning of prosthetic components and semi-automatic measurements of the native anatomy and the simulated implant. The validity of this planning software was assessed in previous papers.[10,11] By using the HipOp-Plan software, 3 conical tapered stems were virtually implanted in every hip by a single author (FC). The 3 stems were selected according to manufacturer descriptions and library availability: Wagner Cone (Zimmer), Alata Acuta (Adler Ortho), Modulus (Lima Corporate, Villanova di San Daniele) (Fig. 1). Wagner Cone (W) is a single-taper conical stem with 12 different diameters and 2 neck-shaft angles (125° and 135°).[12] Alata Acuta (A) is a titanium-on titanium modular stem, with a conical geometry and 12 different diameters.[13] The proximal modularity allows for 27 combinations of 15 exchangeable necks providing 3 independent degrees of offset, length, and version correction: the offset and the length increase by 7.5 mm and the version by 9°. Modulus (M) provides a titanium-on-titanium proximal modularity on a conical design, with 14 stem diameters.[14] The Morse taper connections are available in 2 models, A and B, according to stem diameter. The modularity is available in 4 different models, 2 neck-shaft angles (125° and 135°) and 2 lengths (short and long). The 125° modular part provides a 5 mm lateralization without affecting the center of rotation height. There is also a more enlarged modular part, which is suggested only for stems with diameters of 20 mm or larger.[14] The 3 stem designs share the same conicity (5°) and the 8 longitudinal ribs (Fig. 2).[12-14]

The acetabular component was the Continuum cup (Zimmer), which was used in all the 3 simulations for each case. The cup was implanted in an anatomic position

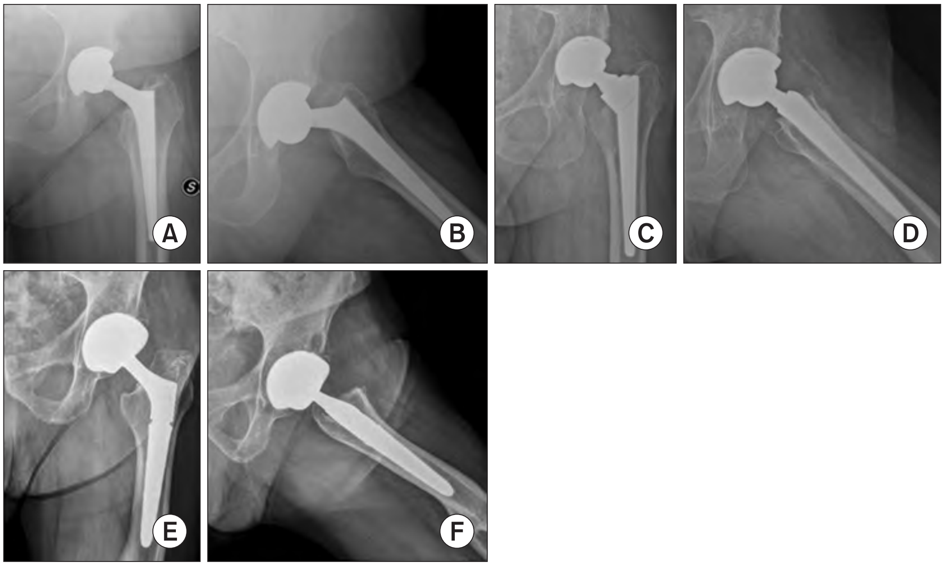

Fig. 1. Anteroposterior and axial x-rays of the 3 implants: Wagner Cone (A, B), Alata Acuta (C,D), and Modulus (E, F).

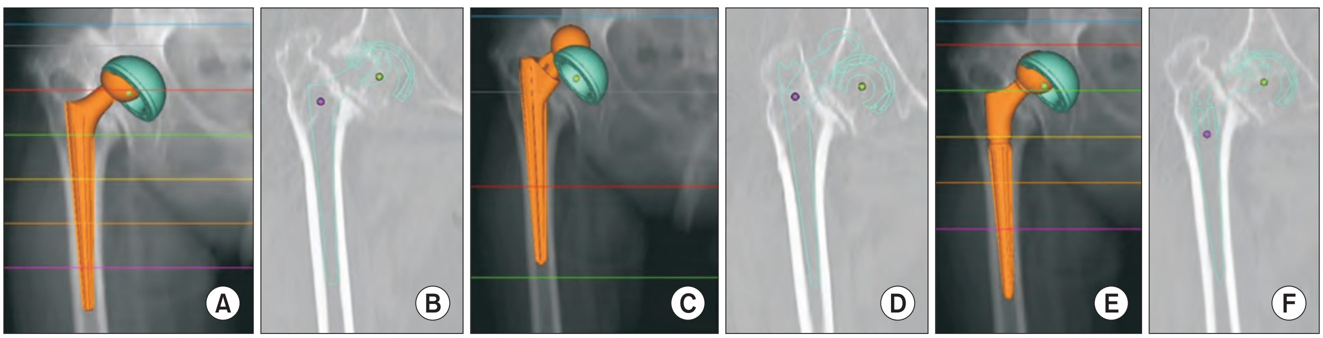

Fig. 2. The same coronal views with the 3 different stems in the Crowe IV hip of a 71-year-old woman: the main features of the stems were evident. (A, B) Single taper W stem. (C, D) Modular neck A stem. (E, F) M stem with proximal modular junction.

whenever possible, aiming to achieve a cup inclination of 40°–45° and an anteversion compatible with the combined anteversion.[11)] Medial protrusion and cup undercoverage exceeding 33% were not permitted.[11)] Anterior cup overhanging was minimized as much as possible.[11)] Cup size, center of rotation height, cup abduction, cup anteversion, and acetabular offset were provided for each case.[11)] Stem implantation aimed to use the most appropriate component to achieve a fitting of the diaphyseal junction of at least 80%, to avoid oversizing, to closely restore the proximal biomechanical parameters (offset, version, and leg length), and to minimize overlengthening without violating the lesser trochanter.[11,15)]

At the end of each simulation, the acceptability of 3D biomechanical reconstruction was assessed by evaluating combined anteversion, femoral offset, stem positioning, canal filling, and leg lengthening according to clinically relevant thresholds inferred from the current literature. Specifically, the following measurements were taken: stem anteversion; femoral offset; sagittal tilt; coronal tilt; canal filling; and leg lengthening.[11,16-18)] To be considered acceptable, the planning had to match all of the below mentioned criteria: combined anteversion according to Dorr et al. between 25°–50° and combined anteversion according to Widmer et al. < 37°; global offset (acetabular + femoral offset) loss not inferior to 12% of the native global offset; coronal and sagittal stem tilt < 5°; canal filling ≥ 80%; and leg lengthening < 3 cm.[11,15-19)] The rationale for choosing these 6 criteria was aimed at defining correct 3D positioning and implantation of the stem: center of rotation reconstruction, offset restoration, leg length equalization, and adequate canal filling.[1,2,11)] To define acceptable numerical thresholds, values were adopted from extensive THA case series with radiological and biomechanical assessments. Failure to meet these thresholds was correlated with poor clinical outcomes or revision surgeries in THAs performed for osteoarthritis or dysplasia.[11,15,17-19] The correct combined anteversion was clinically and biomechanically assessed as follows: outliers were more prone to instability, dislocations, and bearing failure.[11] Loss of offset higher than 12% was correlated with limping and lower clinical outcomes.[18] Coronal and sagittal stem tilt larger than 5° was associated with an increased rate of aseptic loosening over 10 years.[17] Canal filling inferior to 80% was associated with an increased risk of aseptic loosening.[15] Leg overlengthening > 3 cm was correlated with neurovascular damage.[19] The same criteria, with the same cutoffs, were adopted in a previous papers on biomechanical reconstruction provided by 3 different stem designs in dysplastic hips.[11]

Inter- and Intrarater Reliability and Comparison between Simulation and Postoperative Measurements

The inter- and intraobserver reliability for preoperative measurements, even in hip dysplasia, was provided in other papers.[11] The reliability of Hip-Op software simulations compared to postoperative measurements after definitive surgical implants in dysplastic hips was assessed in another paper (perfect agreement).[11] The inter- and intrarater reliability of the simulations, even in dysplastic hips, was assessed in a previous paper.[11]

Demographics and Assessment of the Native Hip Morphology

Sixty-two hips met the inclusion criteria and were selected. One hip could not be simulated using an off-the-shelf acetabular component and was excluded, leaving 61 hips in 55 patients (6 bilateral cases) in the final cohort.

The mean age at CT was 56.26 ± 10.71 years (range, 27–81 years). Eleven out of 55 patients (20%) were men. The mean height was 156.31 ± 9.59 cm (range, 130–170 cm) and the mean weight was 63.79 ± 15.73 kg (range, 42–112 kg). The mean body mass index was 25.97 ± 5.39 kg/m^2 (range, 17.48–37.49 kg/m^2). Left hips were assessed in 31 cases (50.82%). Forty-one hips (67.21%) were classified as Crowe III and 20 (32.79%) as Crowe IV.[9] According to the Hartofilakidis classification, there were 2 B1 (3.28%), 39 B2 (63.93%), 4 C1 (6.56%), and 16 C2 (26.23%) hips.[20] Both classifications were statistically correlated (Kendall $\tau = 0.906$, $p < 0.001$).

The native anatomy of each hip was assessed: center of rotation height, neck-shaft angle, femoral offset, acetabular offset, femoral and acetabular anteversion, leg-length discrepancy, isthmus position, mediolateral and anteroposterior (on axial view) femoral diameters at the isthmus (2 centimeters below the lesser trochanter and 2 centimeters above the lesser trochanter).[11] Anteroposterior (on axial view) and mediolateral canal flares (2 centimeters above the lesser trochanter/isthmus) were assessed.[11] The features of native anatomy are described in Table 1.

Statistical Analysis

The analyses were performed using SPSS 29.0.2 (IBM Corp.). A priori power analysis was conducted (3 cohorts; significance α, 0.05; power $1 - \beta$, 0.80): considering a medium-large effect size (0.4: this was the percentage difference, 90%–50%, among the different stem acceptability of 3 simulated dysplastic cohorts, as obtained in a previous paper), the required number of participants was 60.[11] Quantitative data were reported as average values, standard deviations, and ranges of minimum and maximum. Qualitative data were expressed as frequencies and percentages and tested using chi-square tests. Correlations between parameters were assessed using Kendall and Pearson coefficients or using a logistic regression model depending on the data type. The strength of the correlation was assessed using Nagelkerke's R^2: $R^2 \leq 0.2$ was considered a weak correlation, $0.2 < R^2 < 0.4$ was a moderate correlation, and $R^2 \geq 0.4$ was a strong correlation.[21] Threshold for significance was set at $p = 0.05$.

RESULTS

Cup size was 44 mm in 56 cases (90.16%), 46 mm in 4 cases (6.56%), and 52 mm in 1 case (1.64%).

Implants for Each Stem Design Providing Adequate Reconstruction

The rate of global acceptability (matching all 6 reconstructive parameters) was similar between the 3 stems: W, 52.5% (n = 32); A, 47.5% (n = 29); and M, 55.7% (n = 34) (chi-square $p = 0.66$) (Fig. 3). Considering the reconstructive parameters (combined anteversion, offset restoration, coronal tilt, sagittal tilt, canal filling, and leg lengthening) one by one, none of the stems outperformed the others in any parameter (Table 2, Fig. 4). To investigate a potential benefit provided by modular stems when dealing with complex constitutional offset, offset restoration in the hips (n = 51) with abnormal native offset (normal range, 37 ± 4 mm) was studied.[11] A (84.3%, n = 43) and M (84.3%, n = 43) performed slightly better than W (76.5%, n = 39), with no statistically significant difference (chi-square $p = 0.4$) (Fig. 4).

Table 1. Features of the Native Hips Stratified According to Crowe Classification

Feature of the native hip morphology	Crowe classification		Mean value
	III (41 hips)	IV (20 hips)	
Center of rotation height (mm)	29.34 ± 6.29	48.00 ± 10.97	35.46 ± 11.94
Neck-shaft angle (°)	136.27 ± 15.29	131.85 ± 20.12	134.82 ± 16.98
Femoral offset (mm)	26.22 ± 6.37	26.60 ± 8.16	26.34 ± 6.94
Acetabular offset (mm)	35.61 ± 6.39	39.70 ± 4 .75	36.95 ± 6.17
Acetabular anteversion (°)	15.73 ± 10.26	20.45 ± 11.64	17.28 ± 10.87
Femoral anteversion (°)	34.34 ± 18.98	36.75 ± 18.71	35.13 ± 18.77
Angle between calcar femoral and posterior condyles (°)	42.83 ± 18.79	46.63 ± 25.94	44.03 ± 21.16
Leg length discrepancy (mm)	–11.95 ± 15.00	–23.35 ± 33.19	–15.69 ± 22.98
Mediolateral femoral diameter 2 cm above the LT (mm)	37.29 ± 6.38	32.99 ± 5.56	35.88 ± 6.41
Longest femoral diameter on axial view 2 cm above the LT (mm)	34.01 ± 5.20	33.09 ± 3.03	33.71 ± 4.59
Mediolateral femoral diameter at LT (mm)	23.05 ± 4.61	21.50 ± 5.19	22.54 ± 4.82
Longest femoral diameter on axial view at LT (mm)	33.73 ± 7.30	27.66 ± 5.92	31.74 ± 7.41
Mediolateral femoral diameter just below LT (mm)	18.75 ± 3.86	16.53 ± 2.56	18.02 ± 3.62
Longest femoral diameter on axial view just below LT (mm)	23.26 ± 6.67	21.04 ± 4.58	22.53 ± 6.11
Mediolateral femoral diameter at isthmus (mm)	10.78 ± 2.41	9.92 ± 2.02	10.50 ± 2.31
Longest femoral diameter on axial view at isthmus (mm)	14.57 ± 3.43	13.94 ± 1.91	14.36 ± 3.02
Isthmus position (LT) (mm)	115.20 ± 18.09	107.45 ± 15.59	112.66 ± 17.57
Mediolateral canal flare index	3.66 ± 0.93	3.45 ± 0.75	3.59 ± 0.88
Axial canal flare index	2.93 ± 0.83	2.65 ± 0.63	2.84 ± 0.78

Values are presented as mean ± standard deviation.
LT: lesser trochanter.

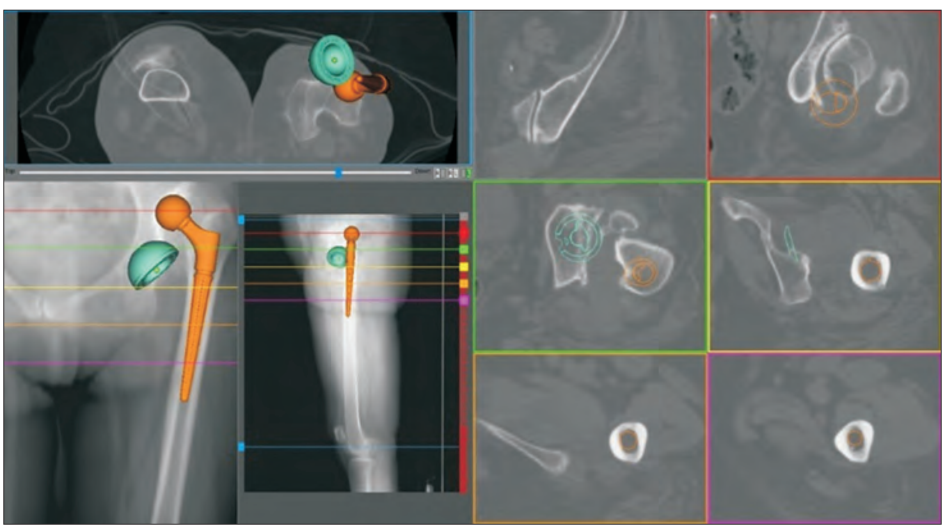

Fig. 3. The M simulation in this Crowe IV hip was not acceptable due to leg overlengthening (45 mm): offset, coronal tilt, sagittal tilt, combined anteversion, and canal filling were all within the acceptable ranges.

Table 2. Acceptability of the Reconstruction for Each Stem Design: the Last Line Shows the Global Acceptability, Matching All 6 Reconstructive Parameters

Reconstructive parameter	Stem design				
	Acceptable	Wagner cone	Alata acuta	Modulus	*p*-value*
Combined anteversion	Yes	60 (98.4)	61 (100)	61 (100)	0.66
	No	1 (1.6)	-	-	
Offset restoration	Yes	42 (68.9)	47 (77)	48 (78.7)	0.40
	No	19 (31.1)	14 (23)	13 (21.3)	
Coronal tilt	Yes	61 (100)	61 (100)	61 (100)	-
	No	-	-	-	
Sagittal tilt	Yes	61 (100)	61 (100)	61 (100)	-
	No	-	-	-	
Canal filling	Yes	61 (100)	61 (100)	61 (100)	-
	No	-	-	-	
Leg lenghtening	Yes	47 (77)	36 (59)	43 (70.5)	0.09
	No	14 (23)	25 (41)	18 (29.5)	
All parameters	Yes	32 (52.5)	29 (47.5)	34 (55.7)	0.66
	No	29 (47.5)	32 (52.5)	27 (44.3)	

Values are presented as number (%).
*Chi-square test.

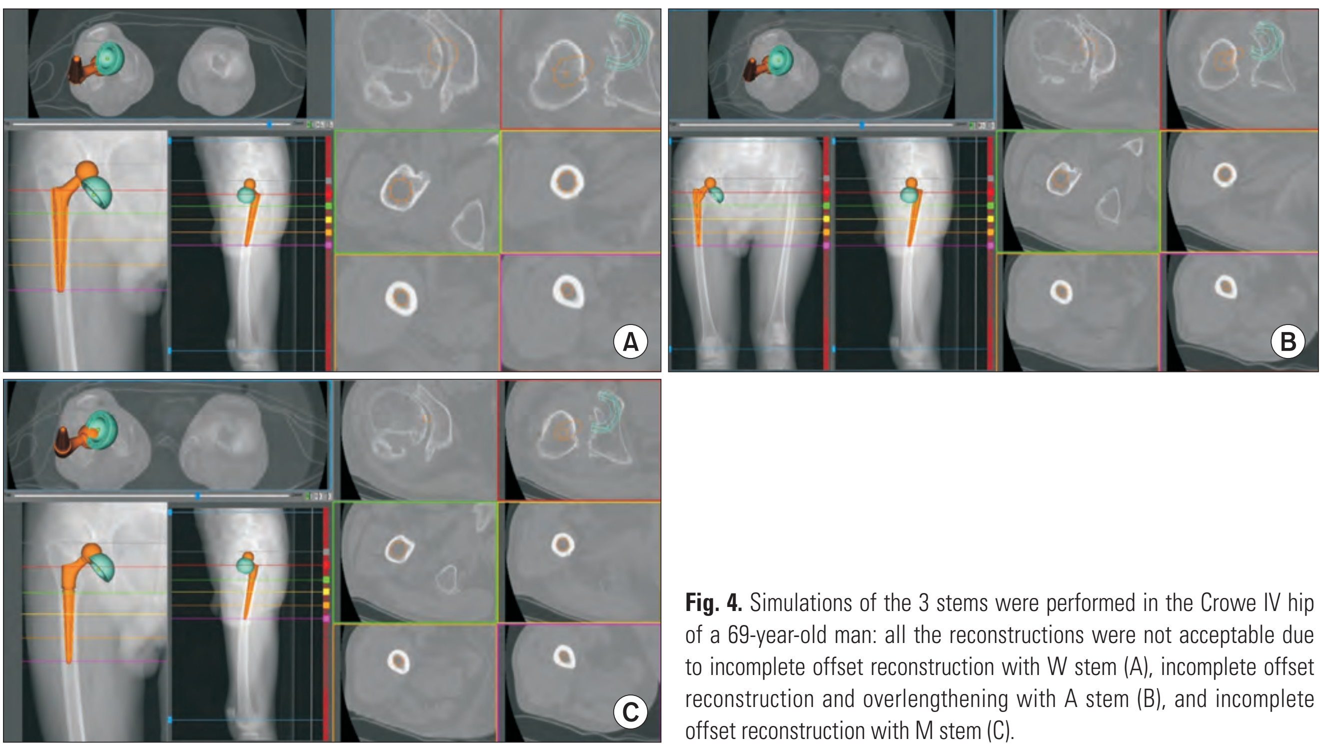

Fig. 4. Simulations of the 3 stems were performed in the Crowe IV hip of a 69-year-old man: all the reconstructions were not acceptable due to incomplete offset reconstruction with W stem (A), incomplete offset reconstruction and overlengthening with A stem (B), and incomplete offset reconstruction with M stem (C).

Correlations between the Reconstruction Provided by Each Stem Design and Native Hip Morphology

A logistic regression model was conducted to determine the native parameters that influence the overall acceptability of the reconstruction, as well as the acceptability of offset and leg length reconstruction for each stem. W's global acceptability was influenced by center of rotation height (inverse correlation, $p < 0.0001$, $R^2 = 0.37$, moderate correlation) and cup medialization (inverse correlation, $p = 0.001$, $R^2 = 0.29$, moderate correlation). Offset restoration acceptability was related to native offset (inverse correlation, $p = 0.008$, $R^2 = 0.19$, weak correlation) and cup medialization (inverse correlation, $p = 0.004$, $R^2 = 0.26$, moderate correlation). Leg length reconstruction acceptability was related to center of rotation height (inverse correlation, $p < 0.001$, $R^2 = 0.48$, strong correlation), neck-shaft angle (direct correlation, $p = 0.034$, $R^2 = 0.11$, weak correlation) and leg length discrepancy (direct correlation, $p = 0.025$, $R^2 = 0.14$, weak correlation).

The global acceptability of A was correlated with center of rotation height (inverse correlation, $p < 0.0001$, $R^2 = 0.37$, moderate correlation), leg length discrepancy (direct correlation, $p = 0.05$, $R^2 = 0.09$, weak correlation), and cup medialization (inverse correlation, $p = 0.02$, $R^2 = 0.13$, weak correlation). Offset restoration acceptability was influenced by native offset (inverse correlation, $p = 0.005$, $R^2 = 0.24$, moderate correlation) and cup medialization (inverse correlation, $p = 0.007$, $R^2 = 0.24$, moderate correlation). Leg length reconstruction acceptability was related to center of rotation height (inverse correlation, $p < 0.001$, $R^2 = 0.48$, strong correlation) and leg length discrepancy (direct correlation, $p = 0.047$, $R^2 = 0.09$, weak correlation).

M's global acceptability was related to center of rotation height (inverse correlation, $p < 0.001$, $R^2 = 0.31$, moderate correlation), canal flare index (direct correlation, $p = 0.029$, $R^2 = 0.14$, weak correlation), and cup medialization (inverse correlation, $p = 0.021$, $R^2 = 0.13$, weak correlation). Offset restoration acceptability was influenced only by native offset (inverse correlation, $p = 0.027$, $R^2 = 0.14$, weak correlation). Leg length restoration acceptability was influenced by center of rotation height (inverse correlation, $p < 0.001$, $R^2 = 0.55$, strong correlation), leg length discrepancy (direct correlation, $p = 0.012$, $R^2 = 0.18$, weak correlation), and cup medialization (inverse correlation, $p = 0.034$, $R^2 = 0.12$, weak correlation).

DISCUSSION

The 3D CT simulations of 3 conical stem designs with different modularity in 61 cases of high-degree dysplasia showed that the 3 implants (single-taper, modular necks, and proximal junction modularity) achieved dependable biomechanical reconstructions (around 50% of 6-parameter acceptability). No significant differences among the 3 stems could be noticed. The main native anatomy feature predictor of inadequate reconstruction was the center of rotation height: the higher the center, the less likely it is to restore leg length equality. The hypothesis was confirmed.

This study has some methodological limitations. This is a 3D simulation study without direct surgical confirmation (provided in another study).[11)] So, the simulated proximal biomechanical reconstructions provided in this study should be considered a good proxy to reality. All the simulations were performed by a single surgeon with expertise in complex joint reconstructions: the inter- and intrarater reliability of these simulations was analyzed in another paper.[11)] The accuracy of 3D planning and simulations was also verified in a dedicated systematic review: the absolute average difference between planned and achieved values of leg length, offset, center of rotation, stem version, cup version, inclination, and abduction were 1 mm, 1 mm, 2 mm, 4°, 7°, 0.5°, and 4°, respectively.[22)] Moreover, the limited cohort size, the Caucasian ethnicity, and the wide variability in anatomic features are other relevant drawbacks. The a priori power analysis was set for medium-large effect sizes (similar to the difference obtained in a previous analogous paper): small differences can be missed, but should be of absent or minor clinical relevance.[11)] On the other hand, the strict selection of high-degree dysplasia and the simulation of 3 different conical stem designs with varying t modularity (single-taper, modular neck, and proximal modular junction) in the same anatomy are 2 main merits of this paper. This type of comparison is not possible *in vivo*; thus. a comprehensive analysis of native anatomy and the 3 simulations provides a unique way to compare different reconstructions in the same anatomy.

While conical tapered stems are now well-known and widely-used components for THA in dysplastic hips, there is a lack of consensus about the indications for the use of modularity.[1,3,11,23,24)] In our study including only Crowe III-IV hips, modular stems (A and M) did not outperform the non-modular stem (W) in terms of proximal anatomy reconstruction; however, all three stems obtained adequate femoral canal filling (≥ 80%) in all simulations. This finding is not in line with the simulation study by Liu et al.,[8] where up to half of the femurs could not be fitted with off-the-shelf conical implants (Wagner Cone and S-ROM, DePuy). On the contrary, our excellent results in femoral fitting are supported by the clinical effectiveness of conical stems in dysplastic femurs.[8,23,24]

The rate of global acceptability for the reconstruction obtained with the 3 stems was nearly identical (W, 52.5%; A, 47.5%; M, 55.7%). Considering the rigorous parameters that had to be matched (combined anteversion according to Dorr between 25°–50° and combined anteversion according to Widmer < 37°, global offset loss not inferior to 12%, coronal and sagittal stem tilt < 5°, canal filling ≥80%, and leg lengthening < 3 cm) and the grade of dysplasia, this can be considered a fairly good performance. The lack of studies with a systematic approach to proximal biomechanical reconstruction prevents any comparison with the literature.

As version in conical implants is completely adjustable, it can be presumed that if a difference between modular and non-modular stems was to be found, it had to be in offset and leg length correction. As a matter of fact, many authors pointed out the great versatility of modular stems in managing these parameters.[1,2,5] Our simulation demonstrated non-inferior performance of the single-taper stem in restoring each parameter. An acceptable combined anteversion was achieved in almost all cases by the 3 stems. As for offset restoration, modular stems performed slightly better, but this difference was not statistically significant (68.9% for W vs. 77% for A and 78.7% for M): this outcome is remarkable considering the well-known difficulties of W in restoring higher native offset.[7,11] Moreover, no relevant differences were found in leg length restoration among modular and single-taper stems: A registered higher percentages of leg length inequality, though not statistically significant. Different from M, A design includes a particular stem groove that does not allow deep stem sinking: the reconstruction of the ultra-varus high-riding configurations is more challenging and fully dependent on the modular neck, resulting in possible leg overlengthening (as demonstrated by the strong inverse correlation between leg lengthening acceptability and center of rotation) (Fig. 3). As these configurations rarely occur even in complex anatomies, the lower percentage of leg length restoration was not significant when compared to the other stems.

There were no native anatomy features favoring a stem design over the others. Global acceptability of the 3 stem simulations mainly depended on native center of rotation height (moderate inverse correlation in all the stems) and cup medialization (moderate to weak inverse correlation). In other words, in high riding dysplastic hips with medialized cups, biomechanical reconstructions achieved lower percentages of global acceptability due to higher rates of leg length inequality at a high center of rotation and incomplete offset restoration when the cup was very medialized. However, both native features (center of rotation height and cup medialization) influenced cup placement more than the femoral reconstruction provided by the stem; no stem could easily compensate for such native conditions. It is worth noting that the reconstructions were not affected by native anteversion, as the conical design is sufficient to correct torsional anomalies.[1,3,7,11,24]

In conclusion, this paper adds further elements for the surgeon to make an informed choice between modular and non-modular femoral components, even in more complex cases such as Crowe III and IV hips. Modular and non-modular stems achieved comparable proximal 3D biomechanical reconstructions, but the modular options slightly improved the native high-offset anatomy restoration. Thus, the use of modular stems in high-grade dysplastic hips does not significantly improve biomechanical reconstruction in most cases and should be carefully evaluated.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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