Arthroplasty Today 14 (2022) 154–162

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original research

Femoral Head Autograft Can Reliably Reconstruct Dysplastic Acetabula Through the Direct Anterior Approach for Total Hip Arthroplasty

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ARTICLE INFO

Article history:
Received 2 August 2021
Received in revised form
16 January 2022
Accepted 12 February 2022
Available online xxx

Keywords:
Femoral head autograft
Hip dysplasia
Total hip arthroplasty
Direct anterior approach
Intraoperative fluoroscopy

ABSTRACT

Background: Bone deficiencies in dysplastic acetabula create technical difficulties during total hip arthroplasty (THA). Bulk femoral head autograft (FHA) is one method to increase cup coverage and bone stock of the true acetabulum; however, only limited data exist on its efficacy through a direct anterior approach (DAA). This study aimed to evaluate the outcomes of FHA during THA via a DAA in dysplastic hips.

Methods: Retrospective review of 34 patients (41 hips) with hip dysplasia (Crowe I-III) who underwent primary THA via a DAA with FHA at a single institution was performed. Surgical procedures were performed on a traction table with intraoperative fluoroscopy and highly porous-coated cup placement in the true acetabulum. Patients were assessed clinically and radiographically at a minimum of 2 years postoperatively (range, 2 to 7).

Results: The average modified Harris Hip Score improved from 31.9 ± 10.8 to 94.1 ± 5.8, Merle d'Aubigné Hip Score from 7.5 ± 2.8 to 16.6 ± 1.1, and visual analog pain score from 7.9 ± 2.7 to 1.4 ± 1.4 (all $P < .001$). All hips had an "anatomic" inferomedial cup position postoperatively, with an average increase in horizontal coverage of 43.4%. Mean postoperative limb-length discrepancy improved from 21.8 ± 16.1 mm to 1.6 ± 5.7 mm ($P < .001$). There were no cases of revision THA, nor complications such as dislocation, infection, or osteolysis.

Conclusion: Reconstructing dysplastic acetabula (Crowe I-III) with FHA during THA can be successfully accomplished via the DAA with increased acetabular bone stock and accurate correction of limb-length discrepancy.

Introduction

Acetabular bone deficiency in patients with hip dysplasia creates technical challenges when performing total hip arthroplasty (THA) and can often preclude conventional placement of the acetabular component. Several techniques to achieve stability and coverage of the acetabular component have been described, including creation of a high hip center [1], cup medialization [2], and reconstruction of the true acetabulum with the use of autograft, allograft, or metal augments [3-7]. Many of these strategies, however, come at the expense of hip biomechanics [8], acetabular bone stock, and/or can be associated with high rates of component loosening [9-11]. As patients with hip dysplasia are often younger with a greater functional demand and higher revision rates than patients with primary osteoarthritis [12-14], optimizing implant longevity, hip biomechanics, and acetabular bone stock is arguably more important for these patients. The use of bulk femoral head autograft (FHA) allows for re-establishment of the true hip center and has the advantage of augmenting bone stock for possible future revisions although its use has historically been controversial due to long-term concerns of graft resorption (Fig. 1) [15-17].

With improvements in surgical technique and the use of highly porous-coated acetabular components, several recent studies have shown promising long-term outcomes of bulk FHA in THA using posterolateral or direct lateral approaches [3-5,18-22]; however,

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https://doi.org/10.1016/j.artd.2022.02.005

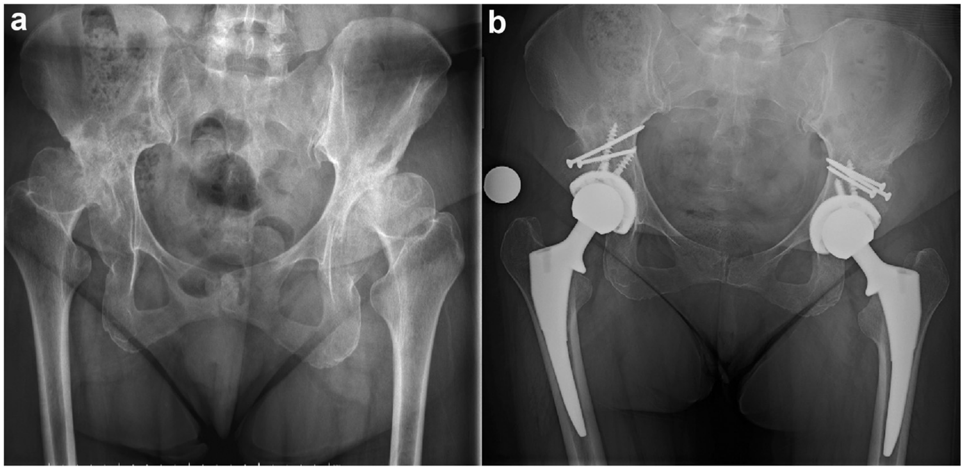

Figure 1. Preoperative (a) and 2-year postoperative (b) anteroposterior radiographs of a patient with bilateral hip dysplasia who underwent bilateral total hip arthroplasty via a DAA with bulk FHA.

limited data exist on its efficacy through a direct anterior approach (DAA). The DAA has become increasingly popular for THA, largely due to minimizing soft-tissue trauma through the use of true intermuscular planes [23]. Advocates of the DAA highlight the potential faster functional recovery with reduced postoperative pain, improved early gait, shorter hospital length of stay (LOS), limited postoperative activity restrictions, and a low dislocation rate [20,24-27]. An additional benefit of the DAA, particularly for dysplastic hips, is that it results in direct exposure of the acetabulum, specifically the anterolateral portion which is commonly deficient in dysplasia [28]. Although the DAA has been associated with a steep learning curve [29], which has largely been associated with difficulty in femoral exposure, this may be overcome with surgeon experience and the use of a traction table [30]. Furthermore, the use of a traction table facilitates fluoroscopy intraoperatively, which allows for real-time feedback on component positioning and correction of limb-length discrepancies (LLD) [31-33].

Given the aforementioned advantages, a few recent studies have reported promising clinical and radiographic outcomes of THA via a DAA in dysplastic hips [10,34-36]. Most of these studies, however, are limited to Crowe IV dysplasia, with variable use of subtrochanteric shortening osteotomies, and inconsistent use of FHA. The purpose of this study is to evaluate the short- to mid-term clinical and radiographic outcomes of primary THA in patients with hip dysplasia (Crowe I-III) performed through a DAA (Hueter) on a traction table with intraoperative fluoroscopy, highly porous-coated acetabular components, and the use of FHA to reconstruct the true acetabulum. The hypothesis is that this technique will provide reliable reconstruction of the true hip center with improvements in clinical outcomes, accurate restoration of LLDs, and increased acetabular bone stock.

Materials and methods

After obtaining institutional review board approval, retrospective review of all patients with hip dysplasia who underwent primary uncemented THA via a DAA with the use of bulk FHA between January 2014 and January 2019 at a single institution was performed as part of the inclusion criteria. Patients who underwent revision THA or who had FHA used to treat alternative etiologies were excluded. Additional exclusion criteria for patient selection included body mass index greater than 40 kg/m^2, hemoglobin A1C greater than 8%, uncontrolled axis 1 or 2 psychiatric disease, severe aortic stenosis or pulmonary hypertension, open leg ulcerations, intravenous drug use within 1 year, active nicotine use, child class B or C liver disease, narcotic use greater than 40 morphine milliequivalents per day, and current homelessness. There were no exclusions for degree of deformity or complexity of the reconstruction. A total of 34 patients (41 hips) met the inclusion criteria. All patients had a minimum of 2 years of follow-up, with no patients lost to follow-up in this series.

Surgical technique

All procedures were performed by a single primary surgeon with consistent use of a traction table (Hana Orthopedic Surgery Table; Mizhuo OSI, Union City, CA) and intraoperative fluoroscopy. A DAA (Hueter interval) was utilized for all patients [37]. Uncemented highly porous-coated titanium acetabular components, press-fit femoral stems, and ceramic femoral heads were used on all patients (Depuy Synthes, Raynham, MA). No conical or modular stems were used in this series.

Preoperative autologous bone graft was always harvested at the time of the index surgery from the ipsilateral femoral head. Graft preparation and fixation were achieved by the following steps (Fig. 2): (1) Femoral head was dislocated prior to completing the femoral neck osteotomy to ensure graft was removed in one piece; (2) native acetabulum was identified by following the ligamentum teres distally to the cotyloid fossa and/or identification of the inferior hip capsule and its relationship to the transverse acetabular ligament; (3) native acetabulum was reamed under fluoroscopic guidance with a small reamer, then the pseudoacetabulum was reamed to remove any cartilage and provide a vascularized bed of bone; (4) the acetabular version was assessed using anteroposterior fluoroscopic images first by obtaining a perfect hemispheric view of the cup and then by assessing the ellipse at the cup opening after the cup positioning arm was moved approximately 20° into anteversion [32]; (5) the final reamer was inserted into native acetabulum, and those with <70% coverage by the native acetabulum proceeded with bulk FHA; (6) femoral head was decorticated with an oscillating saw and burr and shaped into a hemispherical piece to match the convexity of the pseudoacetabulum; (7) graft was oriented such that the subchondral portion of the graft was in maximum contact with the pseudoacetabulum; (8) graft was held in place with a ball spike and

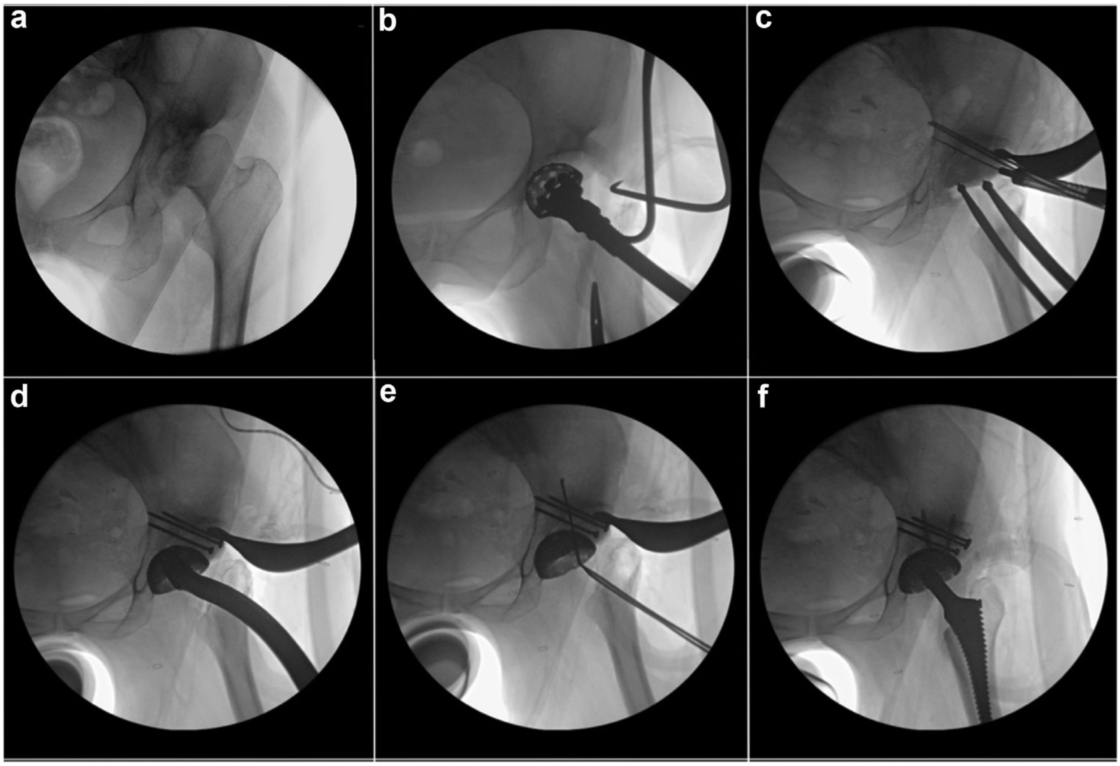

Figure 2. Intraoperative fluoroscopy depicting surgical technique. (a) Anteroposterior fluoroscopy image of the affected hip; (b) native dysplastic acetabulum was reamed, starting with the smallest reamer, to prepare a vascular bed of bone for graft incorporation; (c) hemispherical graft was held in place with two ball spikes and provisionally fixed with three 2.7-mm long drill bits; (d) drill bits were exchanged with 3.5-mm fully threaded stainless-steel screws penetrating the graft and the ilium, and sequential reaming of the acetabulum was performed until the appropriate rim fit into the autograft and host bone was achieved; (e and f) two 6.5-mm titanium screws were placed through the cup, capturing both graft and host bone.

then provisionally fixed with two to four 2.5-mm drill bits penetrating the graft and the inner and outer tables of the innominate bone under fluoroscopic guidance; (9) drill bits were sequentially exchanged for 3.5-mm cortical screws (Depuy Synthes, Raynham, MA); (10) sequential reaming of the acetabulum in its true inferomedial position was performed and under-reamed by 1 mm for appropriate rim fit into the autograft and host bone; (11) depending on graft size and acetabular component size, one to three 6.5-mm fully threaded screws were placed through the cup to capture both graft and host bone for added stability (Fig. 3).

Postoperatively, patients were made touchdown weight-bearing (30 lbs total weight) with no hip precautions on the ipsilateral extremity for 6 weeks, with the aid of two crutches or a walker. Full weight-bearing was allowed after 6 weeks.

Clinical assessment

The preoperative and final postoperative visual analog pain score, Merle d'Aubigné Hip Score [38], and modified Harris Hip Score (mHHS) [39] were recorded for each patient. The requirement for and type of assistive device used during ambulation was also recorded at the initial preoperative and final postoperative visits. All intraoperative and postoperative complications were included.

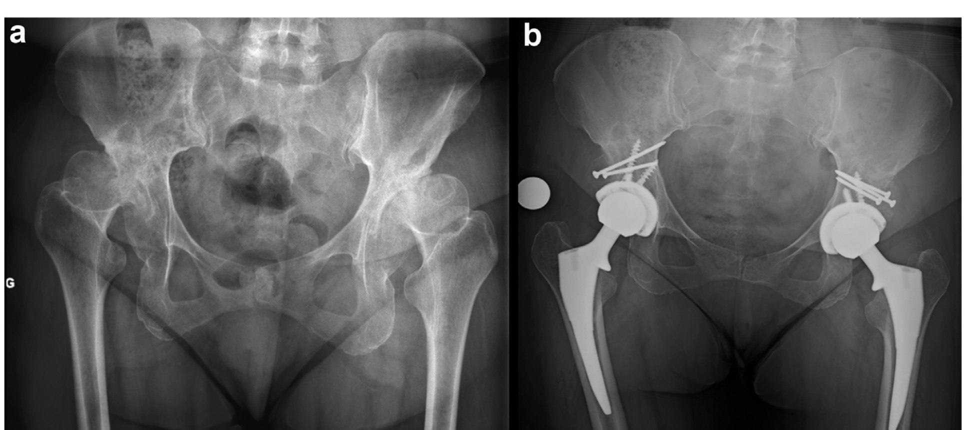

Figure 3. Preoperative and postoperative patient radiographs. Preoperative (a) and postoperative (b) anteroposterior radiographs of a patient with bilateral hip dysplasia who received bilateral THA via DAA with bulk FHA to reconstruct the native acetabulum.

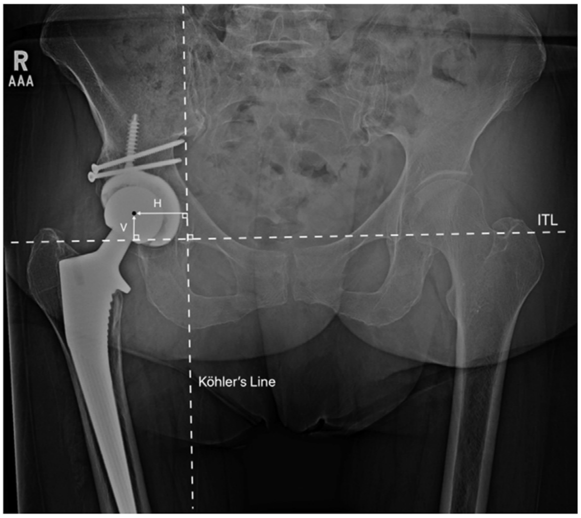

Figure 4. Horizontal and vertical hip center evaluation. Method for measuring the horizontal (H) and vertical (V) positions of the hip center as described by Russotti and Harris [41], where the vertical limb is the perpendicular distance from the interteardrop line (ITL) to the center of the femoral head (black dot), and the horizontal limb is the perpendicular distance from Kohler's line to the center of the femoral head.

Radiographic assessment

The degree of acetabular dysplasia was classified according to the criteria described by Crowe et al. [40]. Anteroposterior radiographs of the hip were taken preoperatively and at every postoperative visit, and all measurements were calibrated with the TraumaCad software system (Voyant Health, Petah Tikva, Israel) and assessed by the senior surgeon (S.N.). Measurement of LLD was evaluated by comparing the position of the midpoint of the lesser trochanter to the interteardrop line on preoperative and final postoperative radiographs. The horizontal and vertical locations of the hip center were measured on postoperative radiographs, as described by Russotti and Harris [41] (Fig. 4), with greater than 35 mm used to define a high hip center [42]. To account for variation in pelvic height, the hip center was also measured using a 4-quadrant system, wherein the midpoint of the horizontal and vertical axes is located 1 cm superior and 1 cm lateral to the approximate femoral head center (AFHC), as described by Pagnano et al. [9] (Fig. 5). The distance lateral and superior to the AFHC was measured, with the inferomedial quadrant considered to be the "anatomic" zone [10].

To account for graft size, the length of the contact zone between the graft and host bone and the graft thickness were measured. The coverage of the acetabular component by native host bone was expressed as the percentage of the horizontal host bone distance and the horizontal distance between the medial and lateral edges of the cup (Fig. 6). At the final follow-up, the horizontal host bone distance included both graft and host bone, if union occurred, which functions as an estimate of the ability of FHA to restore acetabular bone stock. Three center-edge (CE-I-III) angles, as described by Kim and Kadowaki [3], were also used to measure acetabular coverage over time progression (Fig. 7).

Time to graft integration was assessed by the time, in months, when disappearance of the graft-bone interface and the

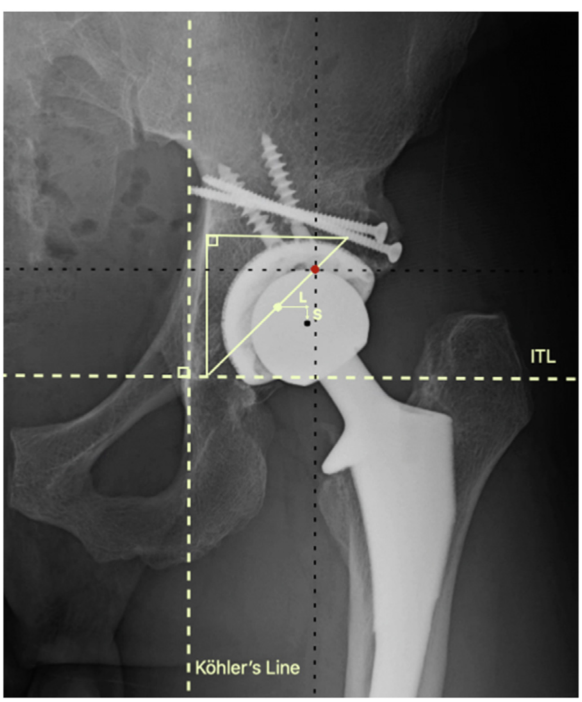

Figure 5. Hip center in relation to the approximate femoral head center. Illustration of the 4-quadrant system (black lines) whose midpoint (red dot) is located 1 cm superior and 1 cm lateral to the approximate femoral head center (AFHC, yellow dot) as described by Pagnano et al. [9]. The AFHC, first described by Ranawat et al. [51], is found at the midpoint of the hypotenuse of an equilateral triangle (yellow solid lines) whose inferior corner is located 5 mm lateral to the intersection of Kohler's line and the interteardrop line (ITL) and whose horizontal and vertical limbs are equal to 20% of the total pelvic height. The distance lateral (L) and superior (S) from the AFHC to the center of the femoral head were measured.

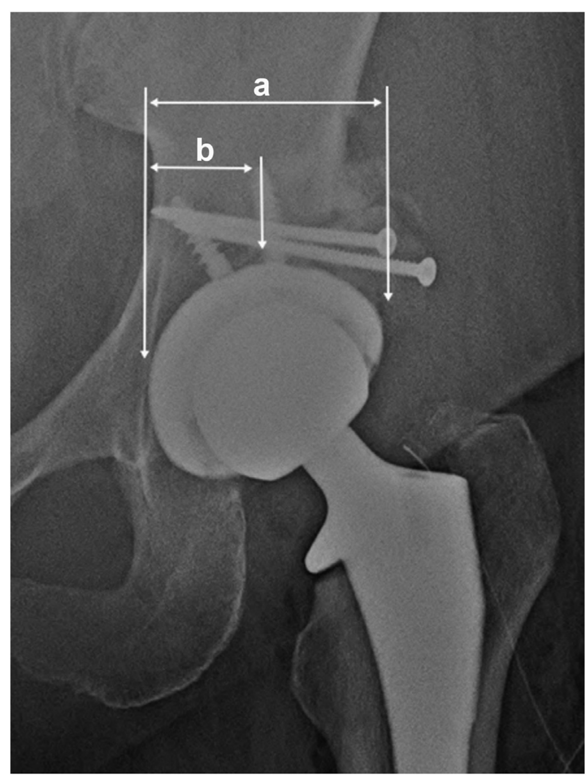

Figure 6. Method for determining horizontal coverage. Radiograph depicting the method for measuring the percentage of horizontal coverage over the cup, calculated as: [horizontal host bone distance (B)/horizontal distance between the medial and lateral borders of the cup (A)] × 100. At the final follow-up, the horizontal host bone distance (B) included both graft and host bone, if union occurred.

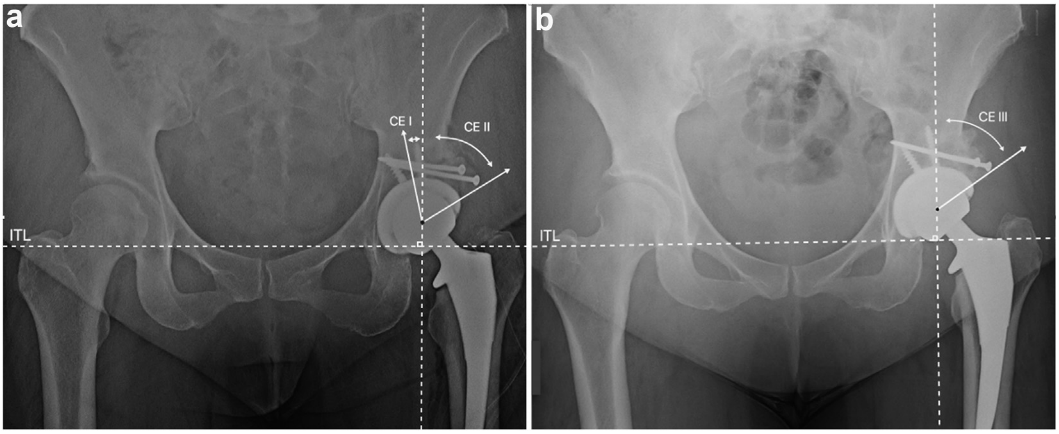

Figure 7. Method for determining center-edge angles. Radiograph depicting method of evaluating graft coverage, as described by Kim and Kadowaki [3]. (a) CE-I: the angle between a vertical line through the center of the femoral head and the lateral edge of the native acetabulum, which was also the medial edge of the graft, immediately postoperatively; CE-II: the angle between a vertical line through the center of the femoral head and the lateral edge of the graft bone immediately postoperatively; (b) CE-III: the angle between a vertical line through the center of the femoral head and the lateral edge of the graft at the final postoperative visit. CE, center-edge angle.

appearance of bridging trabeculae was first observed radiographically. The cup inclination angle was measured as the angle between the interteardrop line and the opening plane of the cup. Radiolucent lines and osteolysis at the acetabular bone-implant interface were recorded as described by DeLee and Charnley [43]. Acetabular loosening was defined as a change in cup inclination angle by >4°, or >2 mm of radiolucency in any of the DeLee and Charnley zones [43].

Statistical analysis

Statistical analyses were completed with SPSS Statistics (version 10.15 for macOS; IBM) using a two-sided level of significance of 0.05. Paired *t*-tests were used in analyzing functional and radiographic outcomes over time progression. Analysis of variance was used to assess for differences in radiographic outcomes by Crowe classification.

Results

For the 31 patients (41 hips) included in this series, 4 hips were classified as Crowe I, 19 hips as Crowe II, and 18 hips as Crowe III (Table 1). The mean follow-up was 3.8 years (range, 2 to 7). The mean age was 49.1 ± 10.2 years with a mean body mass index of 29.0 ± 4.2 kg/m^2. Four patients (6 hips, 14.6%) received prior hip surgery in childhood: 4 proximal femoral osteotomies, and 2 open hip reductions.

Three complications occurred (7.3%), all of which were intraoperative. Two patients had nondisplaced intraoperative calcar fractures, which were treated with a single cerclage wire without further complications. One patient experienced partial vulvar pressure necrosis from the perineal post of the orthopedic table. There were no cases of revision THA due to any cause, nor major postoperative complications such as wound dehiscence, dislocation, infection, or osteolysis.

Clinical outcomes

The mean mHHS improved from 31.9 ± 10.8 to 94.1 ± 5.8, Merle d'Aubigné Hip Score from 7.5 ± 2.8 to 16.6 ± 1.1, and visual analog pain score from 7.9 ± 2.7 to 1.4 ± 1.4 (all $P < .001$) (Table 2). The average hospital LOS was 2.1 ± 1.0 days. All patients required assistive devices for ambulation preoperatively, with 14 patients (41.2%) using a single-point cane, 14 (41.2%) using a front wheeled walker, and 6 (17.6%) relying on a wheelchair (Fig. 8). At the final postoperative visit, only 4 patients used assistive devices (11.7%), all of which were single-point canes.

Radiographic outcomes

Graft incorporation was seen in all patients with the average time to radiographic union of 6.5 ± 4.2 months (Table 3). There was no change in cup inclination angle by >4° or radiolucency >2 mm in any of the DeLee and Charnley zones [43]; however, thin (<1 mm) nonprogressive radiolucent lines were seen in 8 hips (19.5%), with 4

Table 1
Patient demographics and intraoperative data.

Total cohort (41 hips, 34 patients)		
Variables	Value ± SD	Range (%)
Age (y)	49.1 ± 10.2	25 to 70
BMI (kg/m^2)	29.0 ± 4.2	23 to 37
Female gender	28	82.3%
Bilateral surgery	12	29.3%
Non-English primary language	30	88.2%
Prior hip surgery	6	14.6%
Crowe type		
I	4	9.7%
II	19	46.3%
III	18	43.9%
Cup size (mm)	49.8 ± 3.4	46 to 58
Femoral head size (mm)		28 to 36
28	5	12.2%
32	25	61.0%
36	11	26.8%
Number of screws in autograft		
2	23	56.1%
3	16	39.0%
4	2	4.9%)
Number of screws in cup		
1	3	7.3%
2	28	68.3%
3	10	24.4%
Intraoperative complications[a]	3	7.3%

BMI, body mass index; SD, standard deviation.
[a] Incidence of vulvar necrosis and nondisplaced calcar fractures fixed with cerclage wires.

Table 2
Preoperative and postoperative clinical outcomes.

Parameter	Preoperative		Final postoperative		P-value
	Mean ± SD	Range	Mean ± SD	Range	
mHHS					
All patients	31.9 ± 10.8	15 to 45	94.1 ± 5.8	85 to 100	<.001
Crowe I	33.5 ± 12.9	21 to 41	94.9 ± 3.7	92 to 100	<.001
Crowe II	32.4 ± 9.8	15 to 45	94.4 ± 4.9	89 to 100	<.001
Crowe III	25.4 ± 11.1	15 to 42	93.5 ± 6.0	85 to 100	<.001
MDHS					
All patients	7.5 ± 2.8	5 to 11	16.6 ± 1.1	15 to 18	<.001
Crowe I	8.1 ± 2.4	7 to 11	17.1 ± 0.9	16 to 18	<.001
Crowe II	7.9 ± 2.9	5 to 11	16.7 ± 1.5	15 to 18	<.001
Crowe III	7.2 ± 2.3	5 to 10	16.3 ± 1.2	15 to 18	<.001
VAS					
All patients	7.9 ± 2.7	5 to 10	1.4 ± 1.4	0 to 4	<.001
Crowe I	7.2 ± 2.4	5 to 10	1.9 ± 1.7	0 to 3	<.001
Crowe II	7.7 ± 2.5	5 to 10	1.3 ± 1.2	0 to 3	<.001
Crowe III	8.1 ± 1.4	7 to 10	1.6 ± 1.7	0 to 4	<.001

MDHS, Merle d'Aubigné Hip Score; SD, standard deviation; VAS, visual analog scale.

in zone I (9.8%), 2 in zone II (4.9%), and 3 in zone III (7.3%); one patient had radiolucent lines in zones I and II.

The overall mean preoperative LLD was −21.8 ± 16.1 mm, with a significantly greater mean preoperative LLD in patients with higher degrees of dysplasia ($P = .038$) (Table 4). The overall mean LLD improved to −1.6 ± 5.7 mm postoperatively, with no significant difference in the mean postoperative LLD when comparing by Crowe type ($P = .422$). When measuring according to the study by Russotti and Harris [41], the average postoperative hip center was 14.4 ± 8.9 mm in the vertical direction and 25.8 ± 6.2 mm mediolaterally, with no hips having a high hip center postoperatively. The average distance superior to the AFHC was −4.3 ± 4.4 mm, and the average distance lateral to the AFHC was 2.7 ± 2.9 mm with all hips located in the “anatomic” inferomedial quadrant (Fig. 9).

The mean initial horizontal coverage by host bone was 54.4 ± 11.6%, with a significantly lower percentage of initial horizontal coverage in patients with higher degrees of dysplasia ($P = .042$; Table 4). The average horizontal cup coverage at the final postoperative visit was 98.0 ± 4.2%, improving by an average of 43.3%, with no significant difference when comparing by Crowe type ($P = .072$). The average CE improved from −4.6 ± 7.8° preoperatively to 56.1 ± 6.5° immediately after surgery. At the final follow-up, the mean CE-III was 53.4 ± 5.2° with a mean difference from CE-II of 2.7°.

Discussion

This study demonstrates that reconstructing the true acetabulum in dysplastic hips (Crowe I-III) with FHA can be successfully accomplished via a DAA with significant improvements in clinical and radiographic outcomes. Although satisfactory clinical and radiographic outcomes have been demonstrated using similar techniques and indications through alternative surgical approaches [3-5,18-22], potential advantages of the DAA include (1) direct exposure of the anterolateral acetabular defect, that is, typical of dysplastic hips [28]; (2) the use of intraoperative fluoroscopy, which facilitates graft placement and fixation, component positioning, and restoration of LLDs [31-33]; (3) an expedited functional recovery with prior studies demonstrating improvements in early gait, reduced hospital LOS, minimal activity restrictions, a low dislocation rate, and reduced postoperative pain [20,24-26].

To the authors’ knowledge, there is only one published study that included clinical and radiographic outcomes of FHA for dysplastic hips during THA via a DAA [35]. Viamont-Guerra et al. conducted a retrospective review to assess the outcomes of primary THA via a DAA with cup placement in the true acetabulum for 19 patients with severe dysplasia (Crowe III-IV) [35]. Although they demonstrated comparable clinical and radiographic outcomes with a mean postoperative mHHS of 94 and LLD of 3 mm, inconsistent use of FHA, cemented acetabular components, and subtrochanteric

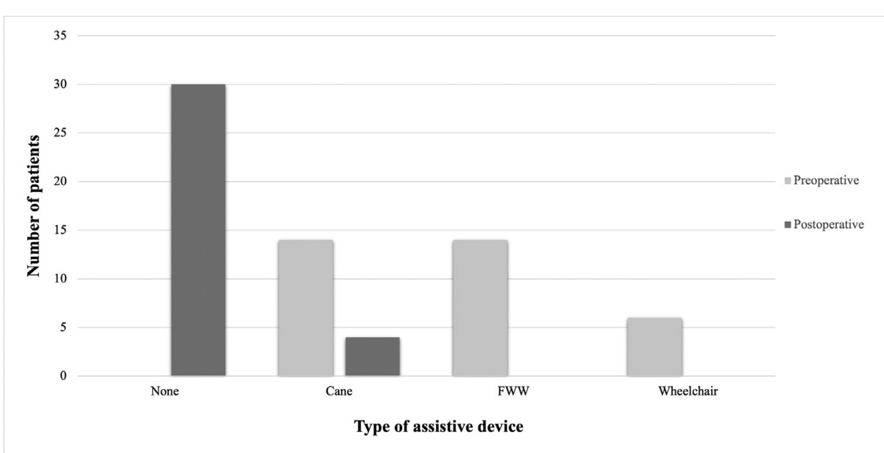

Figure 8. Preoperative and postoperative requirement for assistive devices. Histogram comparing the requirement and type of assistive device used for ambulation preoperatively and postoperatively. FWW, front wheeled walker.

Table 3
Radiographic outcomes.

Parameter	Total cohort (41 hips, 34 patients)	
	Mean ± SD	Range (%)
Autograft size (mm)		
Host-graft contact length	29.3 ± 6.8	27 to 40
Graft thickness	20.4 ± 6.7	12 to 42
Hip joint center (mm)		
Vertical	14.4 ± 8.9	7 to 27
Horizontal	25.8 ± 6.2	18 to 38
Superior to AFHC	−4.3 ± 4.4	−11 to 6
Lateral to AFHC	2.7 ± 2.9	−3 to 9
Inclination angle (°)	39.8 ± 4.4	34 to 47
Horizontal coverage (%)		
Immediate postoperative	54.4 ± 11.6	42 to 64
Final postoperative	97.8 ± 4.1	92 to 100
Limb length discrepancy (mm)		
Preoperative	−21.8 ± 16.1	−38 to −5
Postoperative	−1.6 ± 5.7	−8 to 5
CE (°)		
CE-I	−4.6 ± 7.8	−19 to 0
CE-II	56.1 ± 6.5	47 to 64
CE-III	53.4 ± 6.1	44 to 61
Time to graft incorporation (mo)	6.5 ± 4.2	3 to 12
Radiolucent lines in DeLee zones		
I	4	9.8%
II	2	4.9%
III	3	7.3%

CE, center-edge angle; SD, standard deviation.

shortening osteotomies were performed. In the present series, all patients underwent primary THA via a DAA with the use of a traction table, intraoperative fluoroscopy, FHA, and highly porous-coated cup placement in the true acetabulum. Through this technique, there were no cases of revision THA after 3.8 years of follow-up, with a mean postoperative LLD of only 1.6 mm. This postoperative LLD is improved from alternative surgical approaches using similar patient indications, with a range of 7-29 mm reported in literature [35]. Furthermore, minimal reliance on assistive devices for ambulation was demonstrated postoperatively, and a mean hospital LOS of 2.1 days was achieved, which is well below the national average of 2.8 days for primary THA [44].

Perhaps most importantly, all patients in the present series had reliable reconstruction of the true hip center with all acetabular components being placed in the “anatomic” inferomedial quadrant [10]. As prior studies have demonstrated higher rates of aseptic loosening and acetabular component revision when cups are placed outside of the true hip center [9-11], this is especially important for THA in dysplastic hips. Patients with hip dysplasia requiring THA are often younger, have higher functional demands, and lower overall implant survival than patients with primary osteoarthritis [12-14]. Maximizing implant longevity is therefore critical when approaching these cases, and from a biomechanical perspective, data support inferomedial cup placement [9-11]. The use of bulk FHA not only reconstructs the true hip center but also increased horizontal bone stock by an average of 43.4% in this series, which may prove advantageous in the revision THA setting. Considering alternative techniques, such as creation of a high hip center or use of metal augments, revision THA that could reliably restore hip function in these settings would be potentially challenging owing to limited available bone stock [3]. Furthermore, the use of bulk FHA may provide better graft incorporation potential than allograft [45] and would be less expensive than metal augments or structural allograft [46].

Despite conflicting historical concerns of long-term graft resorption [15], recent literature has been largely positive for FHA [3-5,18-22]. In the present series, there was radiographic evidence of graft incorporation in all patients at a mean time of 6.5 months, which is comparable to alternative surgical approaches [3,4], with no evidence of component loosening or graft collapse. Although the underlying etiology of higher survival rates of FHA in recent literature is unknown, it could be speculated to be from several technical factors including (1) initial graft and cup stability through press-fitting the cup and placement of vertical screws through the cup to capture both graft and host bone; (2) graft orientation such that the subchondral portion of the graft was in maximum contact with the acetabular defect [47]; (3) use of highly porous-coated titanium cups to enhance initial component stability and facilitate bone ingrowth [48]; (4) restoration of the anatomic hip center to allow for a more physiological load transfer to the implant-bone interface [5]. The maximum graft size and extent of host bone coverage has been debated, with some authors recommending >60% [15] or >70% [49] of host bone coverage; however, we found the initial mean percent coverage of the acetabular component by host bone to be 54.4% with satisfactory results.

This report is not without limitations, including its retrospective nature, relatively small cohort size, report of only short- to mid-term outcomes, and reliance on two-dimensional radiographs for assessing bone coverage. Although there were dislocation events postoperatively, there was limitations in the preoperative assessment of femoral and acetabular version as computed tomography scan or other forms of advanced imaging were not routinely performed. Additionally, we recognize that our cohort included 4 patients (9.8%) with Crowe I dysplasia; however, only patients determined to have <70% coverage of the acetabular component intraoperatively received FHA and were included in this series. Furthermore, this series included no cases of Crowe IV dysplasia that required bulk FHA; however, in Crowe IV hips, there is typically less erosion of the acetabular rim than in lower degrees of dysplasia and re-establishment of the true hip center if it is often obtainable with the use of a small acetabular cup alone [50]. We additionally recognize that our outcomes are limited to a mean follow-up of 3.8 years postoperatively, and graft failures have been reported to occur beyond 10 years [15]; however, other authors have demonstrated high long-term rates of FHA survival using similar techniques [3,4,22]. Lastly, this study does not provide a direct comparison to the clinical or radiographic outcomes of similar

Table 4
Radiographic outcomes by Crowe classification.

Crowe type	Number of hips (n)	Limb length discrepancy (mm)		Horizontal coverage (%)		CE (°)		
		Preoperative	Final postoperative	Immediate postoperative	Final postoperative	CE-I	CE-II	CE-III
I	n = 4	−10.8 (−16 to −5)	1.4 (−1 to 2)	58.1 (52 to 64)	98.4 (98 to 100)	−1.5 (−3 to 0)	57.1 (56 to 59)	53.9 (51 to 56)
II	n = 19	−20.7 (−35 to −6)	−1.6 (−8 to 5)	55.3 (50 to 62)	98.1 (95 to 100)	−4.5 (−10 to −1)	56.6 (48 to 62)	54.3 (47 to 61)
III	n = 18	−26.7 (−38 to −10)	−1.8 (−9 to 4)	51.7 (42 to 56)	97.5 (92 to 100)	−4.7 (−19 to −7)	55.2 (47 to 64)	52.2 (44 to 60)
P value		.038	.422	.042	.072	.082	.662	.432

CE, center-edge angle.
All values are expressed as means with ranges in parentheses.

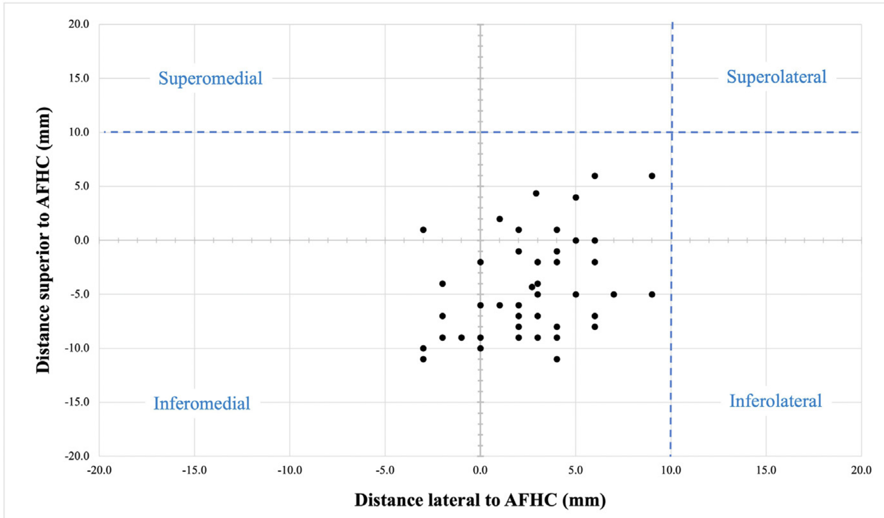

Figure 9. Distribution of hip centers relative to the approximate femoral head center. Scatterplot representing the distribution of hip centers relative to the AFHC. The blue dashed lines represent the 4-quadrant system, as described by Pagnano et al. [9], where the midpoint of the horizontal and vertical limbs are located 10 mm superior and 10 mm lateral to the AFHC, with the inferomedial quadrant considered to be the anatomic quadrant.

techniques done through alternative approaches, which would be an important area of research in future studies. Nonetheless, this series is still the largest and most comprehensively measured cohort, to our knowledge, assessing bulk FHA in THA for hip dysplasia (Crowe I-III) via a DAA. Future studies are necessary to assess the long-term outcomes of this technique.

Conclusions

In conclusion, reconstruction of dysplastic acetabula (Crowe I-III) during THA can be successfully accomplished via a DAA with the use of a traction table, intraoperative fluoroscopy, bulk FHA, and highly porous-coated cup placement in the true acetabulum. Through this technique, significant improvements in mid-term clinical and radiographic outcomes were achieved with reliable restoration of the anatomic hip center and accurate correction of LLDs. This approach also provides additional bone stock for possible future revisions and may demonstrate a substantial cost-saving potential in comparison to alternative options, such as structural allograft or metal augments. Future studies are necessary to further validate the long-term success of this technique.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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