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Total Hip Arthroplasty for the Sequelae of Femoral Neck Fractures in the Pediatric Patient

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ABSTRACT

Although rare, total hip arthroplasty (THA) may be indicated in pediatric patients with degenerative changes of the hip joint after previous trauma. To illustrate management principles in this patient population, this study describes the case of a 15-year-old female who sustained bilateral femoral neck fractures after a generalized tonic-clonic seizure, an atypical, low-energy mechanism for this injury. These fractures were not diagnosed until 14 weeks after the seizure episode, at which point they had progressed to nonunion on the left side, malunion on the right side, and degenerative hip joint changes were developing bilaterally. Bilateral THA was ultimately performed, and the patient had favorable outcomes at 1 year postoperatively. In determining the optimal management strategy for such patients, a multidisciplinary approach should be used, with input from the patient's family, pediatrician, pediatric endocrinologist, pediatric orthopaedic surgeon, and adult reconstruction surgeon. From a surgical standpoint, this report highlights the importance of selecting the appropriate bearing surfaces, broaching technique, mode of implant fixation, and implant features when performing THA in the active pediatric patient.

Introduction

Femoral neck fractures are rare injuries in the pediatric population, accounting for 0.3%-0.5% of all fractures seen in children [1]. These injuries are associated with long-term disability because of their sequelae, which include femoral head osteonecrosis (ON), proximal femoral physeal arrest, nonunion, limb shortening, coxa vara, and chronic degenerative changes of the hip joint [2-6]. The overall rate of these complications ranges from 20% to 60% [2-5,7], with rates of ON reported at 20%-40% after surgical reduction and stabilization [2,6,8,9]. In addition to ON, nonunion occurs in up to 36% of these fractures and is of particular concern in cases of neglected, displaced femoral neck fractures [2].

Total hip arthroplasty (THA) is a procedure rarely performed in pediatric patients, which has resulted in a paucity of published literature on the topic [10,11]. Relative to adults, THA in the pediatric population is performed for a wider array of indications, including pediatric hip diseases, neoplastic conditions, systemic inflammatory disease, osteoarthritis, ON, postinfectious joint degeneration, and hip fracture sequelae [10-12]. Although there are conflicting reports in the literature regarding outcomes of THA in pediatric patients, most studies report favorable medium- to long-term survivorship and significant improvements in patient function after surgery [10-14].

Bilateral THAs are even less common in the pediatric population, with one study on the Nordic Arthroplasty Register Association (NARA) reporting that 18% of all pediatric THAs were bilateral [11]. In such bilateral cases, systemic inflammatory disease was the most common indication, accounting for 43% of all pediatric bilateral THAs [11]. This report describes the case of a 15-year-old female who had a delayed diagnosis of bilateral femoral neck fractures after a seizure. These fractures had undergone malunion and nonunion by the time of diagnosis, and the patient ultimately underwent bilateral THA. To the authors' knowledge, this is the first reported case in the literature of bilateral THA performed in a pediatric patient to treat the sequelae of bilateral femoral neck

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fractures. Several unique components of this case may guide the overall management of pediatric patients undergoing THA, including selection of the appropriate bearing surfaces, broaching technique, mode of implant fixation, and implant features.

Case history

Patient history

A 15-year-old female patient initially presented to the pediatric emergency department for a generalized tonic-clonic seizure that lasted less than 1 minute. Her medical history was significant for severe food allergies and a left femoral shaft fracture that was treated with open reduction and internal fixation 10 years before. The etiology of the seizure was determined to be hypocalcemia from poor oral intake owing to the patient's food allergies. In addition, she had hypovitaminosis D from inadequate intake and limited sun exposure, and her last known vitamin D level was 10 ng/mL. She was stabilized with electrolyte repletion, and the following day, she worked with physical therapy. Although she did report significant, diffuse pain in her bilateral lower extremities with ambulation, she was able to bear weight, transfer, and ambulate short distances with assistance.

Regarding the patient's prior medical state, she had no known history of developmental delay or genetic abnormalities, and she was an active, community ambulator at baseline. However, she did not participate in any sports and was reclusive in her daily activities. Her parents were screened for nonaccidental trauma and neglect by social services at the admitting hospital, and this screen did not raise concern for pediatric abuse. Per the patient's parents, her pediatrician had previously diagnosed her with hypocalcemia and prescribed her calcium and vitamin D supplements, with which she had been poorly compliant. After endocrinology consultation, dual-energy radiograph absorptiometry with follow-up in a pediatric bone health clinic was recommended, and the patient was discharged on hospital day 2.

The patient did not follow up in the orthopedic clinic until 3 and a half months after her injury, at which point, she endorsed persistent bilateral groin pain. A dual-energy radiograph absorptiometry scan performed 2 weeks before demonstrated severe osteopenia, with Z-scores of −3.0 for the hips, −0.6 for the lumbar spine, −4.0 for the femurs, and −4.0 for the total body. The osteopenia was presumed to be due to her poor oral intake and hypovitaminosis D, as she had not been placed on any medications for seizure prophylaxis after her episode. The radiographs of the hips and pelvis were taken for the first time at this clinic visit and demonstrated chronic bilateral femoral neck fractures with evidence of nonunion and severe joint space narrowing on the left side and malunion with moderate joint space narrowing on the right side (Fig. 1). A computed tomography scan with 3D reconstructions was used to better assess these findings and confirm the diagnoses (Figs. 2-5). On both radiographic and computed tomography findings, the patient was noted to be skeletally mature, with evident closure of the bilateral proximal femoral physes and triradiate cartilages.

Physical examination

At the initial orthopaedic clinic visit, the patient was noted to have an antalgic gait and required a cane for ambulation. The left lower extremity had a severe external rotation deformity, and due to a combination of both stiffness and pain, hip flexion was limited 30°, maximum internal rotation could not achieve a neutral position, and abduction was minimal. For the right lower extremity, there was no obvious deformity, passive flexion was limited to 70°, and there was minimal abduction or internal/external rotation secondary to both stiffness and pain. She was neurovascularly intact in the bilateral lower extremities.

Preoperative planning

The patient's parents were counseled on the risks and benefits of operative management of these fractures. Owing to the degenerative changes seen in the left hip joint, THA was deemed to have the most favorable long-term outcomes for the left side. On the right side, initial discussion was directed toward corrective osteotomy, but given the moderate degenerative joint changes and femoral neck deformity, THA was again favored because of more predictable outcomes with less long-term morbidity and risk of reoperation. The family was also counseled on what to expect after bilateral THA. They were informed that in the short term, it may take several months before the patient returned to her preinjury capacity to perform activities of daily living. High-intensity or high-impact athletic activities may prove difficult, and they could also increase the rates of wear and instability, among other complications. Given the existing data on implant survivorship in young and active patients, she would likely require revisions of her THAs at some point in her lifetime, although it would be difficult to estimate the timeframe for this because of a paucity of long-term data on modern implant materials and designs in the pediatric population.

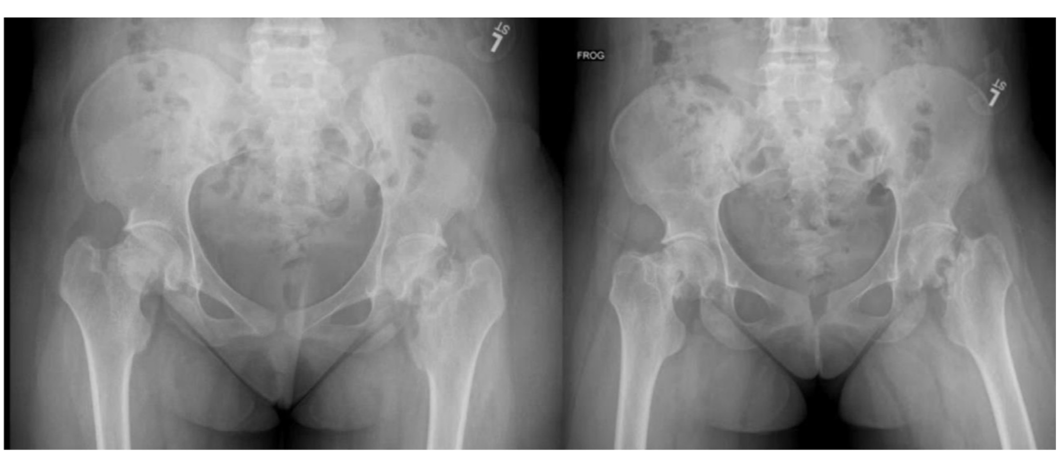

Figure 1. Pelvic radiographs from 14 wk after injury. Anteroposterior (AP) and frog-legged pelvis radiographs demonstrating nonunion of the left femoral neck with severe joint space narrowing. The right femoral neck was suspected to have undergone malunion with moderate joint space narrowing.

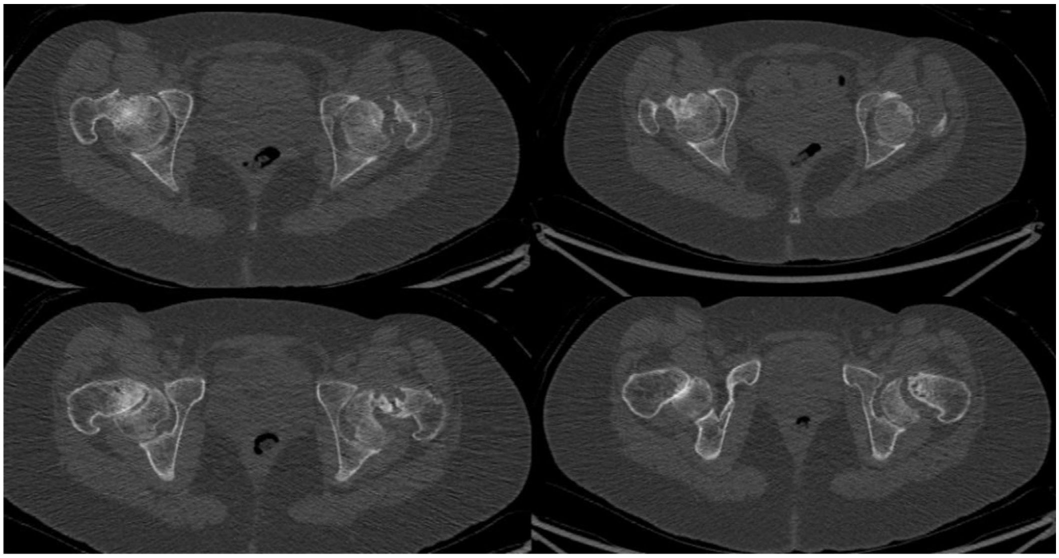

Figure 2. Axial computed tomography (CT) cuts from 14 wk after injury. Axial cuts of the CT pelvis demonstrate nonunion of the left femoral neck with severe joint space narrowing of the left hip. The right femoral neck has a partial union with moderate loss of the right hip joint space. Although true anatomic femoral version cannot be determined with these cuts, both femoral necks appear to have a retroverted orientation. There are cystic changes in both femoral heads, but there are no significant findings suggestive of femoral head osteonecrosis.

Furthermore, they were told that depending on the cause of failure, there may be significant morbidity associated with these revision procedures. Ultimately, informed consent was obtained from the parents, and bilateral, simultaneous THA was scheduled and performed the following week.

Operative technique

The procedure was performed in a 1-stage, sequential fashion, with the left THA performed initially and the right THA performed afterward. Both surgeries were performed from a posterolateral approach, and each side was prepped and draped separately.

After dissecting through the tensor fascia lata, short external rotators, and hip capsule, both hips could be dislocated before making the neck cuts. Both acetabuli were reamed with a size 51 reamer, and size 52 mm DePuy Pinnacle Porous-Coated Cluster Hole cups with Gription (Warsaw, IN) were implanted into each acetabulum. One 6.5×25 mm and one 6.5×20 mm screw were used in each cup, along with $36 + 4$ neutral highly cross-linked polyethylene liners.

On the femoral side, sequential broaching was carried out on both sides without complication, and size 3 and size 2 standard offset DePuy ACTIS (Warsaw, IN) stems were used on the left and right sides, respectively. The broaching technique for this particular stem uses compaction broaching in the anterior-posterior plane but not the medial-lateral plane. A size $36 + 1.5$ ceramic head was used with each stem. Combined anteversion was 50° on the left and 45° on the right, and symmetric leg lengths were achieved. Intraoperatively, both hips were found to be stable at 90° of hip flexion and 90° of internal rotation, as well as in extension and external rotation. In the position of sleep, each hip could internally rotate to 90° before they started to lever out. The capsules and short external rotators were closed as a single sleeve on each side using transosseous suture repair, and the patient was awoken without complication.

Postoperative course

The patient was placed on 40 mg of enoxaparin daily for 6 weeks and allowed to bear weight as tolerated on the bilateral lower extremities with posterior hip precautions. The duration of deep vein thrombosis prophylaxis was per the surgeon's standard protocol and is longer than the upper limit of 35 days recommended by the current clinical practice guidelines [15]. She immediately demonstrated an improved ability to ambulate, cleared physical therapy, and was discharged home with home physical therapy on the day of surgery. At the first follow-up clinic visit 2 weeks postoperatively, she reported that she was comfortable ambulating with a walker and was using a minimal amount of narcotics for pain control. Physical examination of the bilateral hips demonstrated 90° of flexion, full extension, 20° of internal and external rotations, and 30° of abduction and adduction. The radiographs demonstrated proper placement of the femoral and acetabular implants without evidence of hardware loosening or other complications. Leg lengths and offset were near symmetric (Fig. 6). At the 6-week postoperative visit, the patient was comfortable ambulating with a cane, and she had progressed to ambulating without any assistive devices by the 3-month postoperative visit. At the patient's 6-month and 1-year postoperative visits, the patient continued to ambulate without assistance and reported significant improvements relative to her preoperative functional capacity (Figs. 7 and 8). These improvements included no noteworthy pain in either hip, the ability to walk unlimited distances without being limited by her hip replacements, no significant limitations in activities of daily living, the use of a railing with stair climbing, and no limp when ambulating.

Discussion

THA in the pediatric population requires a broad array of additional considerations because of the age and functional demands of these patients. The aforementioned case of bilateral THAs in a pediatric patient consists of a number of unique features, including the patient's young age, atypical mechanism of injury, presence of nonunion and malunion with degenerative changes to the hip joints, and the bilateral nature of the injury and procedure. In the pediatric patient, displaced fractures of the femoral neck have a high complication rate and are associated with long-term disability, even if such fractures are reduced and stabilized in a timely fashion

Figure 3. Sagittal computed tomography (CT) cuts of both hips from 14 wk after injury. (a) Superior images demonstrate sagittal CT of the left femoral neck demonstrating nonunion. The initial fracture appears to have occurred through the transcervical region of the femoral neck. (b) Inferior images demonstrate sagittal CT of the right femoral neck demonstrating malunion. The initial fracture appears to have occurred through the subcapital to transcervical regions of the femoral neck.

[2-5,7]. These complications include femoral head ON, proximal femoral physeal arrest, nonunion, and progression to osteoarthritis.

ON of the femoral head is a well-documented sequela of displaced femoral neck fractures, and it has been found to occur at a frequency of 20%-40% in the pediatric population [2,6,8,9]. Fracture type and location, patient age, fracture displacement, and mode of treatment have all been identified as predictive variables in the development of ON after pediatric femoral neck fracture [7,8,16,17]. Fracture characteristics are of particular importance, as displaced femoral neck fractures are reported to have 9 times the incidence of ON relative to nondisplaced fractures [1,18], whereas transphyseal and transcervical femoral neck fractures (Delbet types I and II) have markedly higher rates of ON in comparison to basicervical or intertrochanteric hip fractures (Delbet types III and IV; Table 1) [1,7,9]. In the present study, the patient's fractures had already progressed to nonunion and malunion, but they appeared to have occurred through the transcervical regions of the femoral neck, conferring a higher risk for femoral head ON. The significant delay in care may have also contributed to the potential for future femoral head ON, but there are numerous conflicting reports in the literature regarding whether accuracy of reduction, capsular decompression, time to surgery, or type of fixation has any bearing on the development of ON postoperatively [1,5-9,16,18]. For this reason, ON is thought to occur chiefly as a result of vascular injury at the time of fracture, either through laceration of the vessels or from tamponade of vascular flow due to increased intracapsular pressure [1]. Because the median time to develop ON after pediatric femoral neck fracture is 7.8 months [18], it would have been too early to determine if our patient had developed femoral ON by the time of bilateral THA. However, given the fact that this patient had numerous risk factors for ON, including advanced pediatric age, displaced fracture, transcervical fracture location, and ambulation on both extremities without operative stabilization of the fractures, it would not have been unusual for this patient to develop femoral head ON bilaterally.

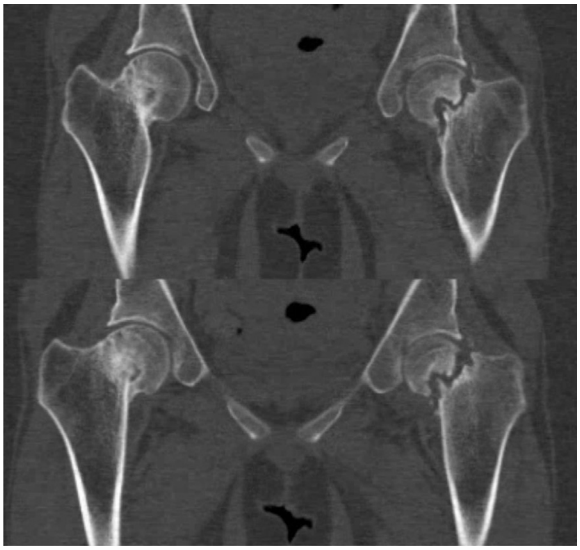

Figure 4. Coronal computed tomography (CT) cuts from 14 wk after injury. Coronal CT of the bilateral femoral necks confirms nonunion of the left femoral neck and a sclerotic malunion of the right femoral neck.

Although numerous methods to treat femoral head ON have been proposed, none have consistently demonstrated reliable outcomes across the existing literature [1,19-23]. These treatment modalities include joint unloading, femoral head core decompression, osteotomy, electrical stimulation, and bone grafting with muscle-pedicle bone grafts, vascular-pedicle bone grafts, and free vascularized bone grafts [1,19-21]. Historically, conservative management and joint unloading were used to treat symptomatic femoral head ON, but these have proven ineffective [22,23]. Core

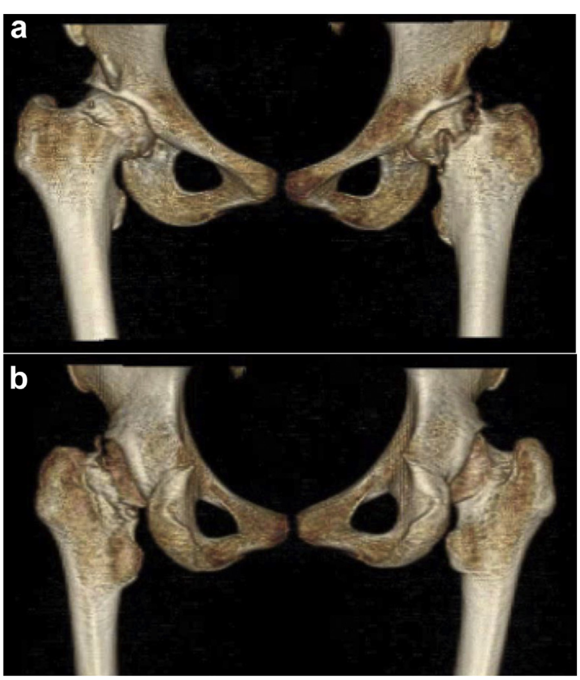

Figure 5. Three-dimensional (3D) pelvis reconstructions. (a) Superior image showing a 3D reconstruction of the anterior pelvis demonstrating nonunion of the left femoral neck and anterior bony union of the right femoral neck. (b) Inferior image demonstrates a 3D reconstruction of the posterior pelvis demonstrating nonunion of the left femoral neck and partial union of the right femoral neck.

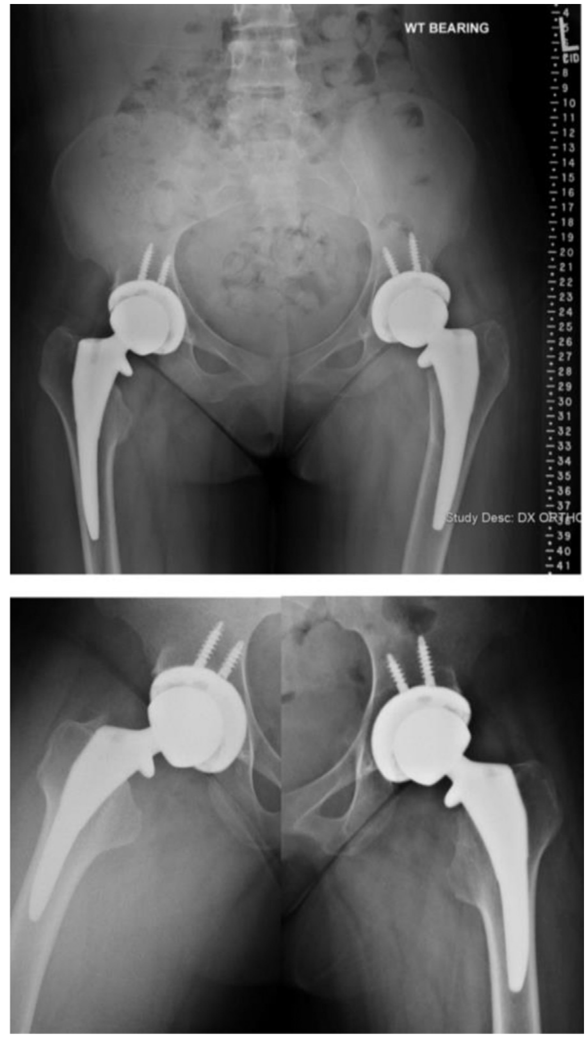

Figure 6. Standing AP pelvis and hip radiographs from 2 wk postoperatively demonstrating appropriate hardware placement with near-equivalent leg lengths and offset. The stem appears slightly proud on the right side because of a lower neck cut necessitated by the previous malunion. AP, anteroposterior.

decompression has been shown in some reports to be effective in earlier stages of ON, but due to the pathology associated with femoral neck fracture sequelae, it is thought to be of limited use for revascularization and bone marrow pressure reduction because the area of necrosis is larger and too far from the site of revascularization [21,24]. Electrical stimulation has shown promise as an adjunctive treatment, but it is unclear if these results are consistently reproducible, making it difficult to recommend its routine use because of the large associated expense [25]. Although osteotomy and bone grafting have shown promising results in select studies, the overall body of evidence is small, much of the existing evidence is from over 25 years ago, and these procedures have not been shown to be reproducible on a larger scale [26-32]. Once femoral head ON has progressed to degenerative changes in the hip joint, the mainstay of treatment is THA [21].

Nonunion is reported to occur in up to 10% of pediatric femoral neck fractures [6]. Nonanatomic reduction, poor or absent fracture fixation, and transcervical fracture location have all been described as risk factors for nonunion [1,6]. In addition to very poor bone health markers, the patient in the present study possessed all of these risk factors, and it is therefore not unexpected that the left femoral neck fracture went on to nonunion. In the absence of other

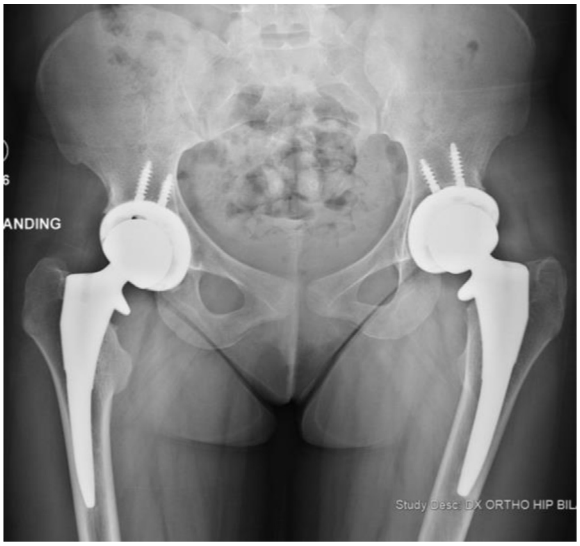

Figure 7. A standing AP pelvis radiograph from 6 mo postoperatively demonstrating stable alignment and hardware positioning. AP, anteroposterior.

complicating factors such as femoral head ON and degenerative joint changes, nonunion of the femoral neck can be managed with the modified Pauwels' intertrochanteric osteotomy [33-37]. This

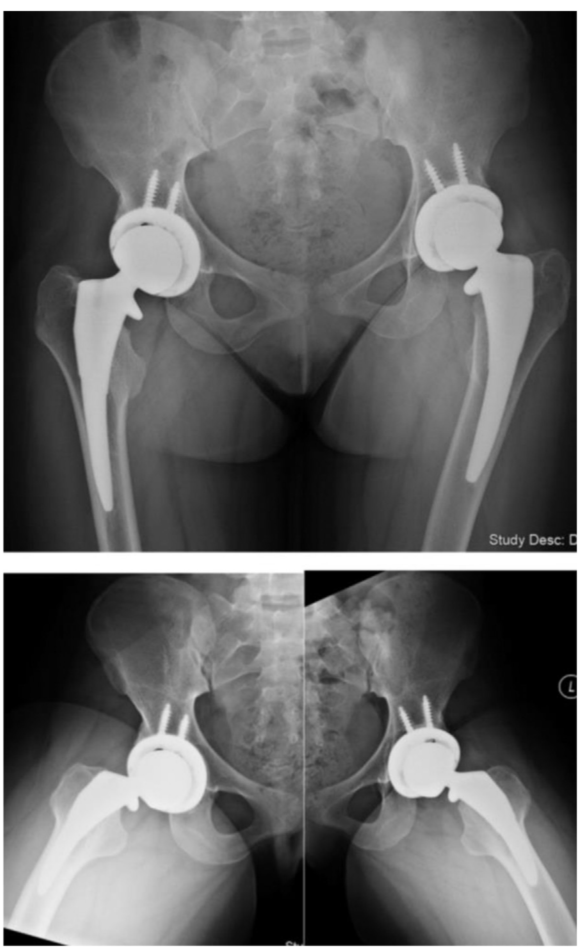

Figure 8. AP pelvis and hip radiographs at 1 y postoperatively demonstrating intact hardware with maintenance of the position and alignment of the implants, with no signs of wear, loosening, or osteolysis. AP, anteroposterior.

Table 1
The Delbet classification of pediatric proximal femur fractures and their associated incidence of femoral head osteonecrosis.

Type	Description	Rate of femoral head osteonecrosis
I	Ia: Transphyseal separation of the proximal femur with associated dislocation of the epiphysis from the acetabulum Ib: Transphyseal separation of the proximal femur without associated dislocation of the epiphysis from the acetabulum	38%-50%
II	Transcervical femoral neck fracture	28%
III	Cervicotrochanteric/basicervical femoral neck fracture	8%-18%
IV	Intertrochanteric proximal femur fracture	5%-10%

valgus osteotomy works by converting shear forces to compressive forces, and a contoured blade plate is typically used to maintain the new neck-shaft angle created by the osteotomy [33-36]. In neglected femoral neck fractures such as in the present case, union rates as high as 100% have been reported after modified Pauwels' intertrochanteric osteotomy [33-36]. This would have been a viable surgical option for our patient, but the rapid development of degenerative changes in the hip joints precluded the use of osteotomy for joint preservation. Osteosynthesis with various muscle pedicle bone grafts or fibular bone grafting has also been described, and although the data are promising, further studies are needed to confirm the long-term efficacy of these procedures [19,20].

Although joint preservation is the preferred choice of management for femoral neck fractures in the pediatric population, the development of degenerative changes of the hip joint, through progression of femoral head ON, altered hip joint biomechanics, or post-traumatic arthritis, ultimately requires joint replacement to create a pain-free, functional hip joint. Sedrakyan et al. [10] performed a literature review of THA in patients younger than 31 years and found that the most common indications for THA were juvenile arthritis, developmental dysplasia of the hip, tumor, trauma, and spondyloepiphyseal dysplasia. Similarly, data from the NARA on 881 THAs in patients aged 21 years or younger found that the primary indications for THA were pediatric hip diseases (33%), systematic inflammatory disease (23%), ON (12%), hip fracture sequelae (7%), and osteoarthritis (4%) [11]. Although our patient's indication for THA was among the top 4 most common indications for THA in the pediatric population, this still represents an exceedingly rare subset of patients.

Overall, the medium- to long-term outcomes of THA in patients younger than 21 years have been largely favorable [10-12,14,38-42]. Sedrakyan et al. [10] reported on total joint arthroplasties performed in pediatric and young adult patients from 1999 to 2012 within the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). They found that in the 297 patients who underwent THA at the age of 20 years or younger, the 5-year revision rate was 4.5% [10]. In an analysis performed by Halvorsen et al. [11] on the NARA database, the unadjusted 10-year survivorship of THA in patients aged 21 years or less was 86%, with no difference in survivorship when compared across THA indications. Of note, 18% of all THAs performed in this age group were bilateral. The primary cause of failure in these patients was aseptic loosening [11], which may be attributed to the pediatric patient's increased activity level relative to the more typical, elderly adult patient undergoing THA.

The choice of bearing surface in the pediatric population is also critical, as these patients have higher functional demands, placing them at increased risk for accelerated wear of their bearing surfaces

[1,14,16]. Daurka et al. [12] reported on the results of 52 consecutive, uncemented THAs performed in patients with juvenile idiopathic arthritis and a mean age of 14.4 years. At a median follow-up of 10.5 years, they found that the 23 ceramic-on-ceramic THAs had a 100% survivorship, whereas the 29 metal- or ceramic-on-polyethylene THAs had a 55% survivorship [12]. Of all revisions performed in this study period, 85% were for revision of the acetabular component because of wear or osteolysis [12], highlighting the importance of pediatric bearing surface selection, even in the age of highly cross-linked, ultra-high-molecular-weight polyethylene (UHMWPE). These findings are corroborated by an older study performed by Bessette et al. [14], who analyzed THAs performed between 1975 and 1990 in patients younger than 21 years. Although these THAs were likely performed with older polyethylene designs, it is noteworthy that nearly every THA in this study demonstrated radiographic eccentric polyethylene wear at a mean follow-up of 13.6 years [14]. The mean Harris Hip Score in this cohort was 64.5, with 53% reporting excellent or good outcomes and 47% reporting fair or poor outcomes at the final follow-up [14]. Finally, Van de Velde et al. [39] analyzed 24 cementless metal-on-polyethylene THAs in patients with a mean age of 14.6 years. At a mean follow-up of 3.8 years, there were no revisions, no evidence of wear or radiographic loosening, and greatly improved pain and function scores [39]. These collective findings suggest that in the pediatric patient, special consideration should be given to both the mode of implant fixation and the type of bearing surfaces.

With respect to bearing surfaces, ceramics have the lowest documented wear rate of any commercially available bearing surfaces and may be particularly beneficial in the active pediatric patient, a notion that has also been demonstrated in the literature [12,43]. Depending on institutional availability, ceramic-on-ceramic or ceramic-on-highly-crosslinked UHMWPE may be the preferred bearing surfaces to ensure implant longevity and minimize the long-term risk of osteolysis [40]. As long as stability is maintained, clinicians may also consider using a smaller head size with a thicker polyethylene liner, as this thicker acetabular bearing surface would extend the timeframe before which the index THA may require revision for wear. For these reasons, a ceramic-on-UHMWPE THA was used in our patient, as this was available at our institution and was thought to provide optimal implant longevity given her young age. Although longer term follow-up studies are needed, the existing evidence suggests that pediatric THA is a safe and effective procedure with largely positive medium- to long-term outcomes when performed using a cementless technique with modern implant designs [12,38,40-42].

Owing to this population's higher functional demands and need for longer implant survivorship, press-fit fixation may be preferred to encourage long-term stability from bony ingrowth rather than relying on cement fixation for the potentially lengthy lifetime of the prosthesis. This is supported by the existing literature, as studies using cementless THA techniques consistently demonstrate improved survivorship relative to those with cemented components [10-12,14,38-42]. Of note, the femoral stem design chosen for the patient in this report uses a compaction broaching technique to preserve cancellous bone stock, and the stem is circumferentially coated with calcium hydroxyapatite to stimulate bone growth; these 2 factors also warrant consideration in a young patient. Furthermore, given the activity level of this population, additional screw fixation in the acetabular component may be beneficial to provide initial stability while bony ingrowth is still occurring. However, it should be noted that acetabular components that allow for screw fixation may exacerbate pelvic osteolysis by increasing the effective joint space [44]. Although this has become a less-prevalent etiology for THA failure with modern polyethylene designs, special consideration is warranted in the pediatric patient who may progressively develop osteolysis over the course of their lifetime [44].

Although THA in the pediatric patient is relatively rare, the patient detailed in this case report underwent bilateral THA, an even less-common procedure. Although the previously described work by Sedrakyan et al. [10] and Halvorsen et al. [11] included bilateral THAs within the analyzed patient data sets, there have been no studies to date that are specific to the long-term outcomes of pediatric patients undergoing bilateral THA. Taheriazam and Saeidinia analyzed the short-term outcomes of bilateral, cementless THA in patients younger than 30 years (mean: 27 years of age) [13]. At a mean follow-up of 4.67 years, the overall complication rate was 3.88%, there were no revisions, and there were significant improvements in all patient-reported outcome measures. However, this study was performed on young adults rather than true pediatric patients, and none of their indications for bilateral THA were for hip fractures or their sequelae [3]. Therefore, it is difficult to draw any definitive conclusions from this work, and the current understanding of the medium- to long-term outcomes of bilateral THA in pediatric patients is best interpreted from the combined unilateral-bilateral THA data from the work of Clohisy et al., the NARA database, and the Australian Orthopaedic Association National Joint Replacement Registry database [10,11,40].

In addition to the patient's delay in care, the presence of femoral neck nonunion and malunion, and need for bilateral THA as a pediatric patient, our case example was also unique in that the patient sustained bilateral femoral neck fractures with an atypical mechanism of injury. The more common mechanism for femoral neck fracture in the pediatric population is high-energy, blunt trauma, such as a high-velocity motor vehicle collision [45]. Even in such instances, the vast majority of femoral neck fractures are unilateral. Bilateral traumatic, pediatric femoral neck fractures are so rare that the incidence is unknown, and any available evidence is limited to single-patient case reports [46,47].

Although we provide the first reported case of bilateral femoral neck fractures caused by a seizure in a pediatric patient, there are several previous reports of such an injury with a similar mechanism in adults [48-52]. The reported incidence of any type of fracture after a generalized tonic-clonic seizure episode is 1.1% [48,53,54]. Most of these fractures involve the proximal humerus [53], and the incidence of femoral neck fractures is currently unknown due to its rarity. Although not all prior case reports of bilateral femoral neck fractures after seizure episodes document a history of poor bone health, it is likely that metabolic derangements contribute to these low-energy mechanisms of fracture. For instance, Nekkanti et al. reported on bilateral, transcervical femoral neck fractures in a 43-year-old male who experienced convulsions from an electrocution injury. On laboratory evaluation, the patient was found to have a vitamin D level of 11.1 ng/mL, highlighting hypovitaminosis D as a potential risk factor for low-energy femoral neck fracture in otherwise healthy, young patients [55]. This was also seen in our patient, who had a vitamin D level of 10 ng/mL in addition to frank hypocalcemia. Therefore, in addition to appropriately managing femoral neck fractures in the pediatric patient, it is prudent for the treating clinician to assess the patient's bone health through clinical judgment and laboratory studies, emphasize the importance of vitamin and mineral repletion if needed, and refer to endocrinology where appropriate. In this case, our patient was cared for by a multidisciplinary team of physicians, including a pediatric endocrinologist and a dietician, to ensure that her long-term bone health was optimized. Finally, the patient in the present study had a delayed diagnosis of femoral neck fracture. Earlier detection and management may have facilitated earlier rehabilitation, decreased the risk of ON and nonunion, and precluded the development of degenerative changes in the bilateral hip joints. In patients who have known metabolic bone disease, clinicians should have a low threshold to radiographically assess areas of pain or dysfunction, as these patients may have potentially devastating fractures caused by atypical, low-energy mechanisms of injury.

Current controversies and future considerations

Femoral neck fractures represent 0.3%-0.5% of all fractures in children [1], with an unknown incidence of bilateral femoral neck fractures due to the great rarity of such injuries. Fracture location (Delbet types I and II), advanced pediatric age, and fracture displacement have all been consistently identified as predictive variables in the development of ON after pediatric femoral neck fracture [7,8,16,17]. There is conflicting evidence regarding whether accuracy of reduction, capsular decompression, time to surgery, or type of fixation has any bearing on the development of ON postoperatively [1,5-9,16,18]. Although numerous modalities for the treatment of femoral head ON have been described, none have consistently displayed favorable and reliable outcomes across the existing literature [1,19-21]. These modalities include femoral head core decompression, osteotomy, electrical stimulation, and bone grafting with muscle-pedicle bone grafts, vascular-pedicle bone grafts, and free vascularized bone grafts [10,19-21]. If hip joint reconstruction is deemed necessary, hip resurfacing (HR) and THA remain the primary treatment modalities [56-61]. HR has had poor results historically [56,61], but more recent studies using meticulous patient selection in young adults have demonstrated satisfactory short- to medium-term outcomes. However, there is conflicting evidence regarding whether patients undergoing HR for femoral head ON have similar outcomes to those undergoing HR for osteoarthritis [21,62,63]. Furthermore, it is worth noting that females may be at increased risk of revision after HR [57,58]. With respect to pediatric THA, emerging evidence demonstrates favorable medium- to long-term outcomes when using cementless techniques and modern implant designs [12,38,40-42]. Future studies should aim to clarify the results of the various joint-preserving procedures for femoral head ON in pediatric patients, as these would be far preferred to hip replacement in such a young population, provided the data support their use. There is also a paucity of long-term outcome data on pediatric THA using cementless techniques and modern bearing surfaces. These patients should undergo follow-up well beyond the typical perioperative period, as they may be increased risk for various complications, given their high functional demands and activity level. Further work should aim to capture the 15- to 20-year follow-up data on this patient population to determine long-term implant survivorship, reasons for failure, and patient-reported outcome measures.

Summary

This study describes the case of a 15-year-old female who underwent bilateral THA to highlight important management considerations in pediatric patients who undergo THA for the sequelae of femoral neck fractures. Numerous aspects of this case were unique, including the low-energy mechanism of injury, metabolic bone disease, delay in diagnosis, presence of nonunion and malunion of the femoral neck fractures, rapid development of degenerative changes in the hip joints, and need for bilateral THA. Although the patient experienced positive short-term outcomes after bilateral THA, earlier detection of the injuries may have delayed the need for THA by allowing for initial reduction and stabilization of the fractures, preventing the development of malunion and nonunion, facilitating early rehabilitation, and maintaining options for potential joint-preserving procedures in the future. In determining the optimal management strategy for these patients, a multidisciplinary approach should be used, with input from the patient's family, pediatrician, pediatric endocrinologist, pediatric orthopaedic surgeon, and adult reconstruction surgeon. If THA is performed in these patients, clinicians should consider using press-fit, highly porous-coated implants to achieve long-term stability and minimize the risk of aseptic loosening. When possible, ceramic bearing surfaces should also be used because of their favorable wear properties, particularly in this young, highly active population. Overall, newer evidence using cementless techniques and modern implant designs demonstrates favorable medium- to long-term outcomes for THA performed in pediatric patients.

KEY POINTS

- Fracture location (Delbet types I and II), advanced pediatric age, and fracture displacement have all been consistently identified as predictive variables in the development of osteonecrosis (ON) after pediatric femoral neck fracture [7,8,16,17]. There is conflicting evidence regarding whether accuracy of reduction, capsular decompression, time to surgery, or type of fixation has any bearing on the development of ON postoperatively [1,5-9,16,18].
- Although numerous methods to treat femoral head ON have been proposed, none have consistently demonstrated reliable outcomes across the existing literature [1,19-23]. These treatment modalities include joint unloading, femoral head core decompression, osteotomy, electrical stimulation, and bone grafting with muscle-pedicle bone grafts, vascular-pedicle bone grafts, and free vascularized bone grafts [1,19-21].
- Pediatric femoral neck fracture nonunion can be treated with the modified Pauwels' intertrochanteric osteotomy, muscle-pedicle bone grafts, or fibular bone grafting [19,20,33-37].
- In addition to appropriately managing femoral neck fractures in the pediatric patient, it is prudent for the treating clinician to assess the patient's bone health through clinical judgment and laboratory studies, emphasize the importance of vitamin and mineral repletion if needed, and refer to endocrinology where appropriate.
- Overall, the medium- to long-term outcomes of THA in patients younger than 21 years have been largely favorable, particularly when using modern implant designs [10-12,37,39-42]. When possible, cementless fixation techniques and ceramic-on-ceramic or ceramic-on-ultra-high-molecular-weight polyethylene bearing surfaces should be used to improve implant longevity.

Conflict of interest

The authors declare there are no conflicts of interest.

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