World Journal of Orthopedics

Submit a Manuscript: http://www.wjgnet.com/esps/
Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
DOI: 10.5312/wjo.v6.i10.776

World J Orthop 2015 November 18; 6(10): 776-782
ISSN 2218-5836 (online)

REVIEW

Surgical management of osteonecrosis of the femoral head in patients with sickle cell disease

Atul F Kamath, Michael H McGraw, Craig L Israelite

Atul F Kamath, Michael H McGraw, Craig L Israelite, Department of Orthopedic Surgery, the Center for Hip Preservation, Penn Medicine, University of Pennsylvania, Philadelphia, PA 19107, United States

Author contributions: Kamath AF, McGraw MH and Israelite CL solely contributed to this paper.

Conflict-of-interest statement: The authors have no conflicts of interest to disclose pertaining to the subject of this review manuscript.

Correspondence to: Atul F Kamath, MD, Department of Orthopedic Surgery, the Center for Hip Preservation, Penn Medicine, University of Pennsylvania, 800 Spruce Street, 8th Floor Preston, Philadelphia, PA 19107,
United States. akamath@post.harvard.edu
Telephone: +1-215-6878169
Fax: +1-215-8292492

Received: May 18, 2015
Peer-review started: May 18, 2015
First decision: August 6, 2015
Revised: August 28, 2015
Accepted: September 16, 2015
Article in press: September 18, 2015
Published online: November 18, 2015

Abstract

Sickle cell disease is a known risk factor for osteonecrosis of the hip. Necrosis within the femoral head may cause severe pain, functional limitations, and compromise quality of life in this patient population. Early stages of avascular necrosis of the hip may be managed surgically with core decompression with or without autologous bone grafting. Total hip arthroplasty is the mainstay of treatment of advanced stages of the disease in patients who have intractable pain and are medically fit to undergo the procedure. The management of hip pathology in sickle cell disease presents numerous medical and surgical challenges, and the careful perioperative management of patients is mandatory. Although there is an increased risk of medical and surgical complications in patients with sickle cell disease, total hip arthroplasty can provide substantial relief of pain and improvement of function in the appropriately selected patient.

Key words: Sickle cell disease; Total hip arthroplasty; Core decompression; Orthopedic; Osteonecrosis; Avascular necrosis; Hip

Core tip: The management of hip pathology in sickle cell disease presents numerous medical and surgical challenges, and the careful perioperative management of patients is mandatory. Key aspects of medical optimization and surgical care are presented in this brief review.

Kamath AF, McGraw MH, Israelite CL. Surgical management of osteonecrosis of the femoral head in patients with sickle cell disease. *World J Orthop* 2015; 6(10): 776-782 Available from: URL: http://www.wjgnet.com/2218-5836/full/v6/i10/776.htm
DOI: http://dx.doi.org/10.5312/wjo.v6.i10.776

INTRODUCTION

Sickle-cell anemia results from a point mutation in the β-globin chain of hemoglobin, replacing the amino acid glutamate with the amino acid valine at the

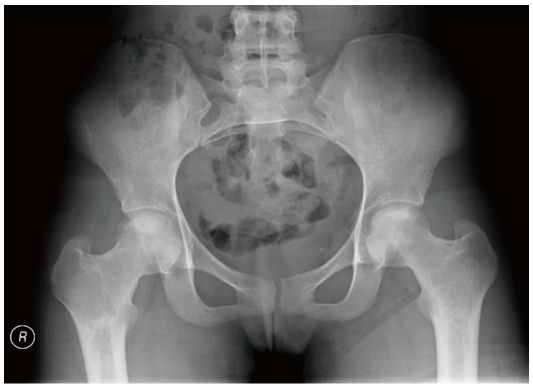

Figure 1 Anterior-posterior radiograph of the pelvis in a 24-year-old female with sickle cell anemia and long-standing, disabling bilateral hip pain.

sixth position. The association of two normal α-globin subunits with two mutant β-globin subunits forms hemoglobin S. Under low-oxygen tension, the abnormal erythrocytes are susceptible to sickling. Clinically, this presents as anemia secondary to intravascular hemolysis and decreased hematopoiesis, and this pathology produces recurrent pain episodes, as well as chronic end organ damage and infarction.

Sickle cell disease (SCD) has a number of orthopedic manifestations, including osteonecrosis of the femoral head (ONFH). To address this pathology and to improve quality of life, a number of surgical options may be entertained. For patients with avascular necrosis (AVN) due to SCD, the hip pathology can be a major limiting factor in terms of level of activity and function. This article serves to outline the evaluation of the painful hip in patients with sickle cell hemoglobinopathy, to review the surgical options available to treat these patients, and to discuss the perioperative complications associated with this patient population.

The sickle cell hemoglobinopathies have a multitude of clinical presentations. Orthopedic insult occurs after chronic end-organ damage. Historically, patients with SCD patients have had a decreased lifespan, and these patients died before boney changes were clinically apparent. With modern day therapeutics and diagnosis, orthopedic manifestations are increasingly evaluated and treated. The specific orthopedic manifestations of SCD and its sequelae include osteonecrosis, infection, and bone marrow hyperplasia. ONFH has been reported to occur in up to 50% of patients with SCD based on the type of hemoglobinopathy[1-4]. It is important to note that, although some demographic groups have mild forms of SCD, such as certain Arab populations, these groups still demonstrate a high frequency of AVN development[5].

Sickling of red blood cells causes vascular congestion, venostasis, and thrombosis in the microvasculature of the bone. Resulting ischemia is compounded by an increase in intraosseous pressure secondary to medullary hyperplasia. This produces bone infarction and necrosis[4]. Patients with symptomatic ONFH typically report groin pain and pain with ambulation. Physical examination reveals painful restrictions in the hip range of motion. Multiple other joints may be affected, including the knees, feet, and back, so a comprehensive examination is important. The hips may be involved bilaterally (Figure 1), and it is not uncommon for necrosis to be asymptomatic, especially in early stages[6]. One study reported radiographic evidence of AVN in the contralateral, asymptomatic hip in 39% of patients with unilateral hip pain[7].

NON-SURGICAL MANAGEMENT

Red blood cell transfusion therapy is used to prevent the primary manifestations of SCD. Transfusion therapy may be warranted for the primary prevention of stroke, chronic pain crises, pulmonary hypertension, chronic renal failure, acute chest syndrome (ACS), and end-organ damage[8].

Hydroxyurea is a widely prescribed drug for management of SCD. It induces HbF synthesis, resulting in decreased sickling and improved red-cell survival. Hydroxyurea is also metabolized into the vasodilator nitric oxide with positive effects on vascular inflammation. Patients with SCD treated with hydroxyurea have significantly fewer acute painful episodes and episodes of ACS, decreased transfusion requirements, and enhanced survival[9,10].

Stem cell transplantation is a novel treatment modality and can be curative in individuals with SCD. Due to inherent risks of the procedure, stem cell transplantation is reserved for patients with significant complications, such as a history of stroke, and those who have a matched sibling stem cell donor[11]. There is more than a 90% survival rate after this procedure and approximately 85% survive free from SCD[12,13].

Many patients with SCD develop AVN of the hip, as well as other synovial joints (knee, foot, and back) despite the advances in medical management. Unfortunately, the natural history of symptomatic AVN of the femoral head secondary to SCD is progressive degenerative changes. Non-surgical management of AVN of the femoral head should be used initially and consists of pain management, activity modification, and ambulatory assistive devices. In addition to plain X-rays, magnetic resonance imaging may be used to assess the severity of femoral head involvement (Figure 2). Non-operative treatments may provide maximal benefit in early stages of disease, prior to collapse of the femoral head articular surface[14].

SURGICAL OPTIONS

Core decompression

The use of core decompression for the treatment of ONFH is controversial because well-controlled prospective trials are lacking. This procedure is reserved for the early stages of AVN (Figure 3). A prospective case-

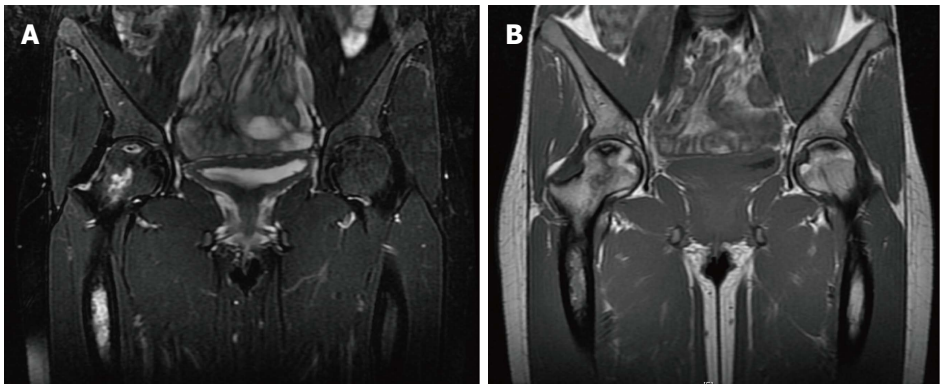

Figure 2 T2-weighted (A) and T1-weighted (B) coronal magnetic resonance imaging sequences demonstrating evidence of bilateral hip avascular necrosis and marrow changes consistent with sickle cell anemia.

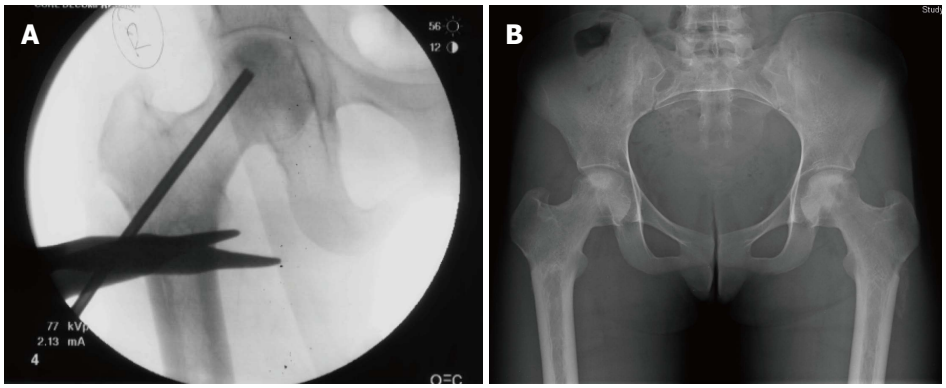

Figure 3 Intra-operative anterior-posterior fluoroscopic view (A) during a core decompression of the right hip, post-operative anterior-posterior radiograph of the pelvis (B) after bilateral core decompression.

Table 1 University of Pennsylvania System for staging avascular necrosis[38]

Stage	Criteria
0	Normal or non-diagnostic radiograph, bone scan, MRI
I	Normal radiographs, abnormal bone scan and/or MRI
	A: Mild (< 15% of femoral head affected)
	B: Moderate (15%-30%)
	C: Severe (> 30%)
II	Cystic and sclerotic changes in femoral head
	A: Mild (< 15% of femoral head affected)
	B: Moderate (15%-30%)
	C: Severe (> 30%)
III	Subchondral collapse (crescent sign) without flattening
	A: Mild (< 15% of articular surface)
	B: Moderate (15%-30%)
	C: Severe (> 30%)
IV	Flattening of femoral head
	A: Mild (< 15% of surface and < 2 mm depression)
	B: Moderate (15%-30% of surface and 2-4 mm depression)
	C: Severe (> 30% of surface and 4 mm depression)
V	Joint narrowing or acetabular changes
	A: Mild[1]
	B: Moderate[1]
	C: Severe[1]
VI	Advanced degenerative changes

[1]Average of femoral head involvement; as determined in stage Ⅳ and estimated acetabular involvement. MRI: Magnetic resonance imaging.

control study showed that core decompression was most efficacious in the early stages of ONFH[15]. Radiographic and clinical outcomes in this study were best in Steinberg Classification (Table 1) stages Ⅰ and Ⅱ. Another study reported symptomatic improvement in eleven of thirteen patients who underwent core decompression in pre-collapse stages[16]. Core decompression combined with autologous bone grafting may provide superior clinical outcomes than core decompression alone: a significant difference in Harris Hip Scores and visual analog scores, at a year post-operatively, were seen in patients who underwent core decompression with bone grafting when compared with core decompression alone[17]. Traditionally, there has been debate regarding whether core decompression should be performed in asymptomatic patients. Hsu *et al*[18] examined thirty-one patients with ONFH who underwent simultaneous bilateral core decompression and grafting. Ten patients with asymptomatic hips at the time of surgical decompression went on to require total hip arthroplasty (THA); thirteen patients required THA in the symptomatic side. The authors found that the proportion of hips ultimately requiring THA were similar between the two groups. When compared to AVN secondary to other etiologies, ONFH secondary to SCD has a poor clinical and radiographic response after core decompression. It has been posited that these inferior results after core decompression are because the decompression may decrease intraosseous pressure but not successfully relieve vascular congestion to prevent future vaso-occlusive events. Furthermore, there are diffuse changes in the femoral head in SCD patients, which may make complete decompression difficult[19]. In a study by Hernigou *et al*[7], more than 40% of the femoral head in SCD was involved, regardless of the stage of ONFH.

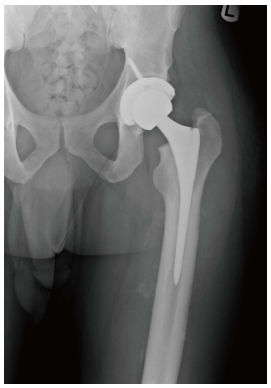

Figure 4 Anterior-posterior radiograph of the left hip in a 36-year-old male status post total hip arthroplasty for end-stage degenerative arthritis secondary to avascular necrosis.

THA

The use of THA for the treatment of ONFH in SCD has increased in popularity and is now the mainstay of the treatment for advanced disease. The primary indication for THA in SCD is persistent, intractable pain of the hip in a patient who has failed non-operative management. The patient must be medically fit to undergo elective surgery[20], and they must understand the post-operative rehabilitation needs, activity restrictions, and complication risks. A well-positioned (Figure 4) and well-functioning THA affords pain relief and functional mobility. Several preoperative considerations are warranted in patients with SCD. It is imperative to prevent crises through appropriate fluid maintenance and adequate oxygenation. Congestive heart failure may be present in some patients with chronic anemia, which requires meticulous attention to fluid balance and co-management with a hematologist familiar with sickle cell patients. Plasmapheresis and preoperative transfusion should be considered to improve oxygen carrying capability. Certain pre-operative hemoglobin levels may decrease the risk of sickle cell related complications[20]. However, aggressive transfusion thresholds may not be necessary: in a series of seventy-four patients, the rate of sickle cell complications did not significantly differ between a conservative (hemoglobin greater than 10 mg/dL) and aggressive (hemoglobin greater than 10 mg/dL; hemoglobin S level less than 30%) transfusion regimen[21]. Transfusion related complications can also be avoided with a more conservative pre-operative transfusion approach. Post-operatively, the SCD patient population is predisposed to infection due to functional asplenia. Periprosthetic and wound infection rates in sickle cell patients after THA have been reported between 16%-20%[22-24]. Remote site infections can seed the prosthesis, and chronic stasis ulcers in patients with SCD are just one of many potential sources of infection[25]. There exists heterogeneity in the series reporting the results of THA in patients with SCD. Multiple studies have demonstrated the effectiveness of THA as a treatment option for disabling pain secondary to ONFH caused by sickle cell hemoglobinopathies. However, complication rates have been reported to be as high as 80% at 6 years[26]. Studies have shown revision rates as high as 63% at 6.5 years post-operatively[23]. On the other hand, several series have shown that THA provides SCD patients pain relief and increased function[22,26-30]. One study reported a significant improvement in Harris Hip Scores, from a mean of 35 points preoperatively to a postoperative mean of 86 points (mean follow-up, 9.5 years)[31]. Another study reported that 73% of patients were without pain and activity restriction at a mean of 8.9 years follow-up[15]. Another series of 244 patients showed that 64% of patients were free of pain: the score for function averaged three points (range, 1-4 points on the Merle D'Aubigne scale) preoperatively and 5.4 points (range, 4-6 points) postoperatively. Furthermore, the score for the cumulative range of motion of the hip averaged 3.1 points (range, 1-6 points on the Postel scale) preoperatively and 5.2 points (range, 4-6 points) postoperatively[30]. Hanker *et al*[23] reported a mean improvement in pain relief at 6.5 years follow-up.

There are few prospective studies comparing cemented *vs* cementless fixation for THA in SCD, and the selection of prosthesis fixation in patients with SCD is controversial. Good results have been demonstrated using cementless THA[24,26,29]. Cementless fixation has potential advantages in patients with SCD. Multiple studies have reported a lower rate of aseptic loosening when using cementless components, which is important in this young patient population[24,26]. At a mean follow-up of 5.7 years, Ilyas reported only one case of acetabular cup loosening in a series of eighteen consecutive patients who underwent bilateral cementless THA[29]. Polymethylmethacrylate cement has also been implicated as a source of high infection rates and septic loosening[27]: The use of cement may cause thermal necrosis, further predisposing the bone to infection and loosening[29]. Several small series have reported a rate of aseptic loosening of 10%-38% in cementless THA[27]. A recent study using cemented components reported an 8% incidence of aseptic loosening[30]. One study reported a 33% aseptic loosening rate in primary THA with cemented cups[27]. A more recent retrospective study reported better results with cemented components[30]. There are some advantages that cemented fixation may provide, including additional hemostasis, decreased risk of femoral perforation and avoidance of biologic fixation in avascular/necrotic bone[20]. Furthermore, the use of cementless components relies on bony ingrowth for fixation in bone that may be largely necrotic. Hip dislocation has also been reported in patients with sickle cell hemoglobinopathy. The rate of hip dislocation has been reported in as many as 26% of hips in one study[26], and may be due to underlying abnormal anatomy seen in patients with SCD.

Alternative surgical options

Other surgical options for the management of AVN in this population include femoral osteotomy, hemiarthroplasty, arthrodesis, and resection arthroplasty. These are

largely historical techniques when compared to core decompression or THA. By redirecting weight-bearing forces, osteotomy can alleviate pressure in discrete areas of the femoral head, but it does not address the underlying pathology and progression of diffuse hip disease. Long-term failure is related to the amount of femoral head involvement[32]. Likewise, hemiarthroplasty only addresses changes in the proximal femur, and the quality of the bone in the SCD acetabulum is often poor. Reciprocal acetabular changes or subsequent migration of the prosthesis into the pelvis have been reported[27,28,33]. Due to the frequency of bilateral hip involvement in ONFH due to SCD, arthrodesis is rarely indicated and leads to significant shortening of the limb after debridement of non-viable bone required for successful fusion. Primary resection arthroplasty is rarely performed because THA provides greater potential benefits, but acceptable results have been reported when used as a salvage procedure after failed primary THA[22].

COMPLICATIONS

Medical and surgical complications are increased in patients with SCD undergoing THA. These complications can be described according to procedural-related complications and those complications specifically related to SCD.

Immediate

An immediate post-operative complication of THA is blood loss requiring transfusion and resulting transfusion reactions. Blood loss during THA in this population is often greater than blood loss seen in patients without the disease. The procedure in patients with SCD may be technically more difficult due to acetabular protrusion, or with difficulties preparing the femoral canal. These challenges may cause an increase in operative time and blood loss. There are also reports in the literature demonstrating that blood loss increases when patients have many preoperative transfusions, alloantibodies, or red blood cell exchange[30,34]. Vichinsky *et al*[21], in a series of 52 patients, reported excessive intra-operative blood loss in the majority of patients who underwent primary THA. The aggressive replacement of blood products is warranted and may decrease cardiopulmonary and neurological complications. It is currently recommended to keep the post-operative hemoglobin in patients with SCD > 10 mg/dL. Likewise, any signs and symptoms of anemia such as tachycardia, syncope, angina, ACS, and hypoxia should be addressed with transfusion[35]. Multiple transfusions throughout the lifetime of these patients lead to alloimmunization. Alloimunization is seen in more than 20% of patients[27]. This accounts for the increased frequency of major transfusion reactions in this population. Hernigou reported an incidence of major transfusion reactions of 12% in his series of primary THA in patients with SCD[30]. Other studies have reported an incidence as high as 4%[24,27].

Other immediate postoperative complications include SCD related events such as vaso-occlusive crises and ACS (17% incidence)[34]. Episodes of vaso-occlusive crisis can present as pain anywhere in the body. Sickle cell crises can be managed with administration of parenteral fluids and analgesics[10,36]. Optimal analgesia is generally achieved with opiates given at pre-determined time intervals or by patient-controlled analgesia. Non-steroidal anti-inflammatories, such as ketorolac or ibuprofen, are also effective but are typically avoided in the immediate post-operative setting secondary to the increased risk of hematoma formation. Other infectious etiologies (*e.g.*, postoperative pneumonia) should be ruled out with appropriate testing.

Acute chest syndrome is a form of acute lung injury in sickle cell patients and presents a major cause of morbidity and mortality[36]. The diagnosis of ACS is clinical and involves the presence of a new pulmonary infiltrate on chest X-ray, along with respiratory tract symptoms, hypoxemia, and/or fever. Intubation and mechanical support may be necessary if the symptoms progress. Acute chest syndrome is associated with a high mortality; therefore, an aggressive treatment strategy should be initiated early. This treatment includes aggressive oxygenation, analgesics, antibiotics as needed, and/or simple or exchange transfusions[37]. Incentive spirometry should also be encouraged through out the peri-operative period.

Short term

Patients with SCD are predisposed to infection. Studies have reported postoperative wound infections in 16%-25% of THAs[23,35]. A first generation cephalosporin should be used for antibiotic prophylaxis in these patients. No empiric coverage of *Salmonella* is generally necessary. However, authors have recommended the frequent use of intraoperative bone cultures to rule out infection before implanting the prosthesis[29]. Patients with SCD also have increased development of wound complications including increased wound drainage and hematoma formation, and complication rates have been reported in the literature[27].

Late

Late peri-prosthetic infection is a particular concern for patients with SCD because recurrent bacteremia is commonly seen and may result in hematogenous seeding of the prosthesis[30]. The risk of late infection has been reported and may ultimately require resection arthroplasty for treatment. Hernigou *et al*[30] reported that late infection, at a rate of 3%, was the main complication in his series. Late infection was the reason for resection arthroplasty in 100% of patients in another study[22]. Small series have reported rates of non-infectious (aseptic) prosthetic loosening of 10%-38%[27]. The reliance on bony ingrowth for fixation in necrotic

bone with cementless implants may be the cause of this phenomenon. A recent study using cemented components reported a lower incidence of aseptic loosening (8%) and posited that a properly placed cemented component may decrease the risk of aseptic loosening[30]. Hip dislocation is also a late complication, and has been reported in patients with sickle cell hemoglobinopathy. The rate of dislocation has been reported in as many as 26% of hips, and may be due to the changes in the bony anatomy seen in patients with SCD[26].

CONCLUSION

Avascular necrosis of the femoral head due to SCD can be quite debilitating. The surgical management of hip pathology in patients with SCD can be challenging, as there is an increase in medical and surgical complications in this patient population. To ensure a successful outcome, it is imperative that the surgeon consider all perioperative management strategies, including a multi-disciplinary approach to care with medical, anesthesia, and hematology colleagues. In early stages of ONFH, core decompression with or without bone grafting is a viable option to attempt to prevent progression of the disease. In patients with intractable pain and advanced disease, primary THA is the most reliable option for pain relief and functional improvement. The evaluation of the hemodynamic and oxygenation status of the patient minimizes sickle cell related complications in those undergoing operative interventions. Modern day cementless THA components have demonstrated encouraging outcomes in SCD patients. Total hip arthroplasty in the appropriately selected patient with SCD can provide improved hip function and enhanced quality of life.

REFERENCES

1 **Chung SM**, Alavi A, Russell MO. Management of osteonecrosis in sickle-cell anemia and its genetic variants. *Clin Orthop Relat Res* 1978; **130**: 158-174 [PMID: 639388 DOI: 10.1097/00003086-197801000-00016]

2 **Chung SM**, Ralston EL. Necrosis of the femoral head associated with sickle-cell anemia and its genetic variants. A review of the literature and study of thirteen cases. *J Bone Joint Surg Am* 1969; **51**: 33-58 [PMID: 4884827]

3 **Milner PF**, Kraus AP, Sebes JI, Sleeper LA, Dukes KA, Embury SH, Bellevue R, Koshy M, Moohr JW, Smith J. Sickle cell disease as a cause of osteonecrosis of the femoral head. *N Engl J Med* 1991; **325**: 1476-1481 [PMID: 1944426 DOI: 10.1056/NEJM199111213252104]

4 **Matos MA**, dos Santos Silva LL, Brito Fernandes R, Dias Malheiros C, Pinto da Silva BV. Avascular necrosis of the femoral head in sickle cell disease patients. *Ortop Traumatol Rehabil* 2012; **14**: 155-160 [PMID: 22619100]

5 **Adekile AD**, Gupta R, Yacoub F, Sinan T, Al-Bloushi M, Haider MZ. Avascular necrosis of the hip in children with sickle cell disease and high Hb F: magnetic resonance imaging findings and influence of alpha-thalassemia trait. *Acta Haematol* 2001; **105**: 27-31 [PMID: 11340250 DOI: 10.1159/000046529]

6 **Mont MA**, Zywiel MG, Marker DR, McGrath MS, Delanois RE. The natural history of untreated asymptomatic osteonecrosis of the femoral head: a systematic literature review. *J Bone Joint Surg Am* 2010; **92**: 2165-2170 [PMID: 20844158 DOI: 10.2106/JBJS.I.00575]

7 **Hernigou P**, Bachir D, Galacteros F. The natural history of symptomatic osteonecrosis in adults with sickle-cell disease. *J Bone Joint Surg Am* 2003; **85-A**: 500-504 [PMID: 12637438]

8 **Wanko SO**, Telen MJ. Transfusion management in sickle cell disease. *Hematol Oncol Clin North Am* 2005; **19**: 803-826, v-vi [PMID: 16214645 DOI: 10.1016/j.hoc.2005.07.002]

9 **Steinberg MH**, McCarthy WF, Castro O, Ballas SK, Armstrong FD, Smith W, Ataga K, Swerdlow P, Kutlar A, DeCastro L, Waclawiw MA. The risks and benefits of long-term use of hydroxyurea in sickle cell anemia: A 17.5 year follow-up. *Am J Hematol* 2010; **85**: 403-408 [PMID: 20513116]

10 **Voskaridou E**, Christoulas D, Bilalis A, Plata E, Varvagiannis K, Stamatopoulos G, Sinopoulou K, Balassopoulou A, Loukopoulos D, Terpos E. The effect of prolonged administration of hydroxyurea on morbidity and mortality in adult patients with sickle cell syndromes: results of a 17-year, single-center trial (LaSHS). *Blood* 2010; **115**: 2354-2363 [PMID: 19903897 DOI: 10.1182/blood-2009-05-221333]

11 **Walters MC**, Storb R, Patience M, Leisenring W, Taylor T, Sanders JE, Buchanan GE, Rogers ZR, Dinndorf P, Davies SC, Roberts IA, Dickerhoff R, Yeager AM, Hsu L, Kurtzberg J, Ohene-Frempong K, Bunin N, Bernaudin F, Wong WY, Scott JP, Margolis D, Vichinsky E, Wall DA, Wayne AS, Pegelow C, Redding-Lallinger R, Wiley J, Klemperer M, Mentzer WC, Smith FO, Sullivan KM. Impact of bone marrow transplantation for symptomatic sickle cell disease: an interim report. Multicenter investigation of bone marrow transplantation for sickle cell disease. *Blood* 2000; **95**: 1918-1924 [PMID: 10706855]

12 **Bernaudin F**, Socie G, Kuentz M, Chevret S, Duval M, Bertrand Y, Vannier JP, Yakouben K, Thuret I, Bordigoni P, Fischer A, Lutz P, Stephan JL, Dhedin N, Plouvier E, Margueritte G, Bories D, Verlhac S, Esperou H, Coic L, Vernant JP, Gluckman E. Long-term results of related myeloablative stem-cell transplantation to cure sickle cell disease. *Blood* 2007; **110**: 2749-2756 [PMID: 17606762 DOI: 10.1182/blood-2007-03-079665]

13 **Panepinto JA**, Walters MC, Carreras J, Marsh J, Bredeson CN, Gale RP, Hale GA, Horan J, Hows JM, Klein JP, Pasquini R, Roberts I, Sullivan K, Eapen M, Ferster A. Matched-related donor transplantation for sickle cell disease: report from the Center for International Blood and Transplant Research. *Br J Haematol* 2007; **137**: 479-485 [PMID: 17459050 DOI: 10.1111/j.1365-2141.2007.06592.x]

14 **Hungerford DS**, Jones LC. Asymptomatic osteonecrosis: should it be treated? *Clin Orthop Relat Res* 2004; **492**: 124-130 [PMID: 15577476]

15 **Mukisi-Mukaza M**, Manicom O, Alexis C, Bashoun K, Donkerwolcke M, Burny F. Treatment of sickle cell disease's hip necrosis by core decompression: a prospective case-control study. *Orthop Traumatol Surg Res* 2009; **95**: 498-504 [PMID: 19801210 DOI: 10.1016/j.otsr.2009.07.009]

16 **Styles LA**, Vichinsky EP. Core decompression in avascular necrosis of the hip in sickle-cell disease. *Am J Hematol* 1996; **52**: 103-107 [PMID: 8638629 DOI: 10.1002/(SICI)1096-8652(199606)52:2<103: : AID-AJH6>3.3.CO; 2-K]

17 **Chang T**, Tang K, Tao X, Cao H, Li H, Chen Q, Chen L, Zhou J, Zhou B, Xu J. [Treatment of early avascular necrosis of femoral head by core decompression combined with autologous bone marrow mesenchymal stem cells transplantation]. *Zhongguo Xiufu Chongjian Waike Zazhi* 2010; **24**: 739-743 [PMID: 20632513]

18 **Hsu JE**, Wihbey T, Shah RP, Garino JP, Lee GC. Prophylactic decompression and bone grafting for small asymptomatic osteonecrotic lesions of the femoral head. *Hip Int* 2011; **21**: 672-677 [PMID: 22038309 DOI: 10.5301/HIP.2011.8760]

19 **Moran MC**. Osteonecrosis of the hip in sickle cell hemoglobinopathy. *Am J Orthop* (Belle Mead NJ) 1995; **24**: 18-24 [PMID: 7773653]

20 **Jeong GK**, Ruchelsman DE, Jazrawi LM, Jaffe WL. Total hip arthroplasty in sickle cell hemoglobinopathies. *J Am Acad Orthop Surg* 2005; **13**: 208-217 [PMID: 15938609]

21 **Vichinsky EP**, Neumayr LD, Haberkern C, Earles AN, Eckman J, Koshy M, Black DM. The perioperative complication rate of

orthopedic surgery in sickle cell disease: report of the National Sickle Cell Surgery Study Group. *Am J Hematol* 1999; **62**: 129-138 [PMID: 10539878 DOI: 10.1002/(SICI)1096-8652(199911)62:3<129: : AID-AJH1>3.0.CO; 2-J]

22 **Bishop AR**, Roberson JR, Eckman JR, Fleming LL. Total hip arthroplasty in patients who have sickle-cell hemoglobinopathy. *J Bone Joint Surg Am* 1988; **70**: 853-855 [PMID: 3392082]

23 **Hanker GJ**, Amstutz HC. Osteonecrosis of the hip in the sickle-cell diseases. Treatment and complications. *J Bone Joint Surg Am* 1988; **70**: 499-506 [PMID: 3356716]

24 **Acurio MT**, Friedman RJ. Hip arthroplasty in patients with sickle-cell haemoglobinopathy. *J Bone Joint Surg Br* 1992; **74**: 367-371 [PMID: 1587879]

25 **Gunderson C**, D'Ambrosia RD, Shoji H. Total hip replacement in patients with sickle-cell disease. *J Bone Joint Surg Am* 1977; **59**: 760-762 [PMID: 908699]

26 **Hickman JM**, Lachiewicz PF. Results and complications of total hip arthroplasties in patients with sickle-cell hemoglobinopathies. Role of cementless components. *J Arthroplasty* 1997; **12**: 420-425 [PMID: 9195318 DOI: 10.1016/S0883-5403(97)90198-4]

27 **Moran MC**, Huo MH, Garvin KL, Pellicci PM, Salvati EA. Total hip arthroplasty in sickle cell hemoglobinopathy. *Clin Orthop Relat Res* 1993; **294**: 140-148 [PMID: 8358906 DOI: 10.1097/00003086-199309000-00018]

28 **Clarke HJ**, Jinnah RH, Brooker AF, Michaelson JD. Total replacement of the hip for avascular necrosis in sickle cell disease. *J Bone Joint Surg Br* 1989; **71**: 465-470 [PMID: 2722941]

29 **Ilyas I**, Moreau P. Simultaneous bilateral total hip arthroplasty in sickle cell disease. *J Arthroplasty* 2002; **17**: 441-445 [PMID: 12066273 DOI: 10.1054/arth.2002.31084]

30 **Hernigou P**, Zilber S, Filippini P, Mathieu G, Poignard A, Galacteros F. Total THA in adult osteonecrosis related to sickle cell disease. *Clin Orthop Relat Res* 2008; **466**: 300-308 [PMID: 18196410 DOI: 10.1007/s11999-007-0069-3]

31 **Al-Mousawi F**, Malki A, Al-Aradi A, Al-Bagali M, Al-Sadadi A, Booz MM. Total hip replacement in sickle cell disease. *Int Orthop* 2002; **26**: 157-161 [PMID: 12073108 DOI: 10.1007/s00264-002-0337-5]

32 **Schneider W**, Aigner N, Pinggera O, Knahr K. Intertrochanteric osteotomy for avascular necrosis of the head of the femur. Survival probability of two different methods. *J Bone Joint Surg Br* 2002; **84**: 817-824 [PMID: 12211671 DOI: 10.1302/0301-620X.84B6.12837]

33 **Berend KR**, Lilly EG. Early acetabular protrusio following hemiresurfacing of the hip for osteonecrosis in sickle cell disease. *J South Orthop Assoc* 2003; **12**: 32-37 [PMID: 12735623]

34 **Vichinsky EP**, Haberkern CM, Neumayr L, Earles AN, Black D, Koshy M, Pegelow C, Abboud M, Ohene-Frempong K, Iyer RV. A comparison of conservative and aggressive transfusion regimens in the perioperative management of sickle cell disease. The Preoperative Transfusion in Sickle Cell Disease Study Group. *N Engl J Med* 1995; **333**: 206-213 [PMID: 7791837 DOI: 10.1056/NEJM199507273330402]

35 **Garden MS**, Grant RE, Jebraili S. Perioperative complications in patients with sickle cell disease. An orthopedic perspective. *Am J Orthop* (Belle Mead NJ) 1996; **25**: 353-356 [PMID: 8727085]

36 **Bakanay SM**, Dainer E, Clair B, Adekile A, Daitch L, Wells L, Holley L, Smith D, Kutlar A. Mortality in sickle cell patients on hydroxyurea therapy. *Blood* 2005; **105**: 545-547 [PMID: 15454485 DOI: 10.1182/blood-2004-01-0322]

37 **Miller ST**. How I treat acute chest syndrome in children with sickle cell disease. *Blood* 2011; **117**: 5297-5305 [PMID: 21406723 DOI: 10.1182/blood-2010-11-261834]

38 **Steinberg ME**, Steinberg DR. Classification systems for osteonecrosis: an overview. *Orthop Clin North Am* 2004; **35**: 273-283, vii-viii [PMID: 15271535]

P- Reviewer: Robertson GA **S- Editor**: Qiu S **L- Editor**: A
E- Editor: Lu YJ

Published by **Baishideng Publishing Group Inc**
8226 Regency Drive, Pleasanton, CA 94588, USA
Telephone: +1-925-223-8242
Fax: +1-925-223-8243
E-mail: bpgoffice@wjgnet.com
Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
http://www.wjgnet.com