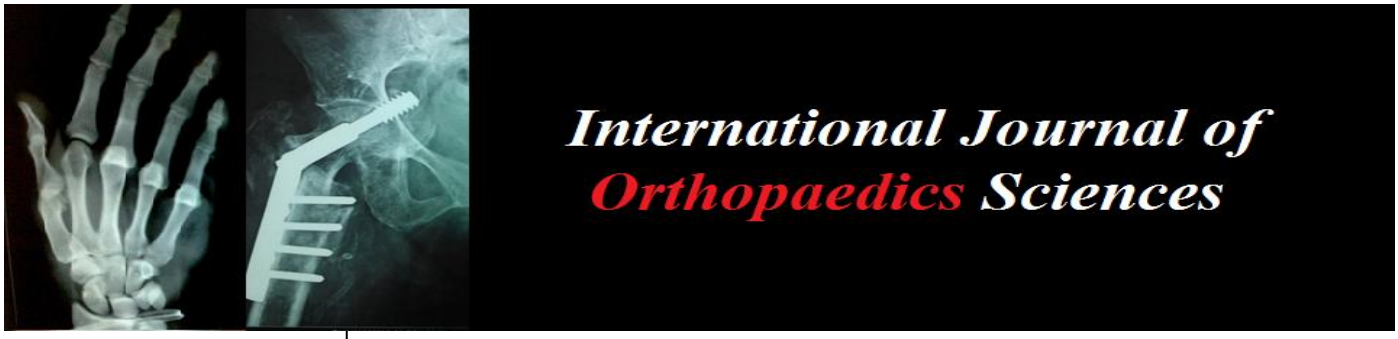


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# Modified technique of percutaneous core decompression with flexible reamers and percutaneous iliac bone graft harvesting for treatment of femoral head osteonecrosis

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**Abstract**
Avascular necrosis of the femoral head (ANFH) is a debilitating disease most commonly affecting young and middle-aged people. Most often leading to a significant articular disability, ultimately needing a total hip replacement. Early diagnosis and effective joint-preserving surgical treatments are urgently needed for patients with early stage ANFH. We would like to report a minimally invasive modified technique of percutaneous core decompression using flexible reamers and percutaneous iliac bone graft harvesting to treat the early stage of femoral head osteonecrosis.

**Keywords:** Osteonecrosis of the femoral head, avascular necrosis hip, flexible reamer for core decompression, percutaneous bone graft with hollow mill

## Introduction
Avascular necrosis of the femoral head is a destructive condition most commonly affecting young and middle-aged people. This often progresses to femoral head collapse and often requires total hip arthroplasty [1, 4]. Even though the exact etiology is still unclear, the risk factors have been well documented in the literature and they are chronic corticosteroid administration, chronic alcohol ingestion, smoking, and various chronic diseases (renal disease, hematological disease, inflammatory bowel disease, post organ transplantation, hypertension, and gout) [5, 6]. Clinically early stages of AVN are painless, which on progression will result in severe groin associated with limitation of hip movement and collapse of femoral head, ultimately leading to hip arthritis [5, 6]. There are many treatment options in the early stages of the disease before the head collapses, including nonsurgical, pharmacological and surgical treatments. However, there is little evidence on supporting nonsurgical treatment when the condition is identified in the early stages. Nonweight bearing is often used for symptom relief but does not seem to alter disease progression [7, 8].Pharmacologic treatments of AVN consist of bisphosphonates, anticoagulants, vasodilators, statins, and biophysical modalities like ESWL, ultrasound was also reported [9]. Bisphosphonates are indicated up to the stage of early collapse. They inhibit the osteoclastic activity in the osteonecrotic lesion site, thus promoting bone healing and preventing collapse or fracture of subchondral bone [10, 11]. Commonly studied bisphosphonate is oral alendronate, and is reported to be effective in reducing the collapse rate by over 50% compared to the placebo groups at doses of 10 mg/day or 70 mg/wk [12]. The current state of nonsurgical treatment options for ANFH is still in the experimental stage.
The most common surgical treatment is core decompression for early stage disease. Of late core decompression with bone grafting (with or without adjuvants) is being followed. THA is the main stay of treatment for the advanced stage of ANFH and in whom conservative or joint-preserving surgical treatments have failed. THA has excellent outcomes in terms of pain relief, survivorship and quality of life [2, 4, 13]. However, young patients with ANFH who have undergone THA are most likely to experience implant loosening and revision surgery in their lifetime [14]. Therefore, the most suitable time to intervene in the early stage of the disease.

(ARCO classification stage 1 and 2. The ideal goal of early stage treatment is to postpone or stop the progression of the disease before the mechanical failure of the subchondral bone and collapse of the femoral head. A consensus has been reached that joint preserving surgeries should be followed in the early stage and arthroplasty for the advanced stage [15].

Core decompression is a joint-preserving surgical treatment that aims to improve blood flow and decrease intraosseous pressure for relieving pain. It promotes early healing prior to collapse, thereby potentially postponing or avoiding THA [4, 16]. But studies have shown that the femoral head after simple decompression alone may not provide structural support and as a result, the risk of femoral head collapse increases [17, 18].

Core decompression combined with bone grafting has been used to treat ONFH since the mid-twentieth century to prevent femoral head collapse by providing structural support and establishing a stable environment for the growth of new bone [19]. The clinical outcome of core decompression with bone grafting for the early stage of ONHF has been confirmed [3].

Kong *et al.* [20] studied the outcome of percutaneous core decompression with bone grafting on ANFH. They concluded that this method can be used to effectively treat the early stage of ANFH. This treatment modality can also significantly relieve symptoms, improve the movement of the hip, and postpone or stop the femoral head collapse. Zalavras *et al.* [3] treated 17 hips in 15 patients with core decompression with autologous bone graft, and allogenic fibula perfused with human bone morphogenetic protein and noncollagenous proteins. Through a mean follow-up of 53 months, 14 of 15 hips (93%) had relief of outcomes and no radiographic progression.

The aim of this article is to introduce a minimally invasive modified surgical technique of core decompression using flexible reamers and percutaneous iliac bone graft harvesting for early stage ANFH.

## Materials and Methods

The clinical data of 23 patients and 23 hips diagnosed with ANFH were included in the study and treated with the procedure called percutaneous core decompression and percutaneous bone graft technique at santhiram general hospital from july 2017 to march 2021. All were prospectively analyzed; the follow-up ended in December 2021. The followup period was 2 yrs.

### Inclusion criteria

1. All patients with the stage II of the ARCO classification system (figure 1). confirmed by MRI.
2. The boundary of avascular necrosis in the femoral head was clear
3. Good hip range of motion in order to maintain the requirements of the intraoperative position.

### Exclusion criteria

1. AVN following Trauma and metabolic diseases were excluded. 2. Bilateral AVN

The outcome was evaluated by the Harris hip score (HHS), visual analogue scale (VAS), radiography changes preoperative and postoperative.

| Stage | 0 | I | II | III | IV |
|---|---|---|---|---|---|
| Finding | All present techniques normal or nondiagnostic | X-ray and CT are normal, at least one of the blew mentioned is positive | No crescent sign, X-ray abnormal: Sclerosis, osteolysis, focal osteoporosis | Crescent sign or collapse on the X-ray and/or flattening of articular surface of femoral head | Osteoarthritis joint space narrowing, acetabular changes, joint destruction |
| Techniques | X-ray; CT; Scintigraph; MRI | Scintigraph; MRI; Quantitation on MRI | X-ray; CT; Scintigraph; MRI; Quantitation on MRI and X-ray | X-ray; CT; Quantitation on X-ray | X-ray |
| Sub-classification | NO | LOCATION<br>medial central lateral<br>  | | | NO |
| Quantitation | NO | Area involvement (%); minimal A: < 15%; moderate B: 15%-30%; extensive C: > 30% | Length of crescent (%); A: < 15%; B: 15%-30%; C: > 30% | Collapse and Dome depression; A: < 15% / < 2 mm; B: 15-30% / 2-4 mm; C: > 30% / > 4 mm | NO |

**Fig 1:** Association Research Circulation Osseous classification system

**Informed consent statement:** All participants provided written informed consent

### Surgical technique

A single surgeon (author) performed all surgeries with the patient supine on a traction table under spinal anesthesia.

Best Entry point was determined under image intensifier guidance. A 2 cm skin incision was given. The entry point was always above the level of the lesser trochanter. A 2.5 mm rigid guide wire was drilled into the lesion area and confirmed in AP and Lateral views. Initially reaming done with 4 mm rigid reamer till the top of the lesion. serial reaming with 6, 7, to 8 mm reamers done till the base of the lesion only. Now the ACL (anterior cruciate ligament) femoral guide (stryker) was introduced into the tunnel and flexible guide wire was drilled into the superior and lateral portion of the lesion till the top border of the lesion. Later serial reaming is done with versitomic flexible reamer (stryker USA) starting from 4 mm till 9 mm depending on the size of the lesion. Now the ACL guide is reintroduced into the inferior and medial direction and a similar procedure is followed till almost the entire sclerotic necrotic bone is removed. Residual sclerotic necrotic bone from the edges of the lesion can be cured with 15 degree curette. All these steps must be performed under C-arm fluoroscopy in both AP and lateral views to make sure that the instruments were placed in the best possible position without damaging the articular cartilage and retaining the healthy bone as much as possible. The drilling channels were flushed using a combination of irrigation and suction. Finally, the lesion area and the surgical operation created bone defect

were backfilled with graft. We take the appropriate amount of cancellous bone and bone marrow aspirate (20ml) from the patient's ipsilateral ilium thru a 1.5cm incision by percutaneous technique, using a 6mm hollow mill. First a 2mm k wire was introduced to a depth of 1 cm. Tap the hollow mill over k wire to prevent slipping from the iliac crest. Hollow mill was drilled slowly till 3cm. toggle it and reverse drill it out. Follow a similar technique till optimum graft is obtained. We mix both autologous bone and tricalcium phosphate and bone marrow aspirate. After adding the BMA, the mixture was introduced into the lesion area and drill channels through a drill sleeve used for proximal lag screw locking of PFN. The mixture was tapped by a pestle. The incision was closed by the standard steps. After the operation they were put on non-weight-bearing for 6 wk. and oral bisphosphonate, alendronate 70 mg weekly for 3 years to be continued.

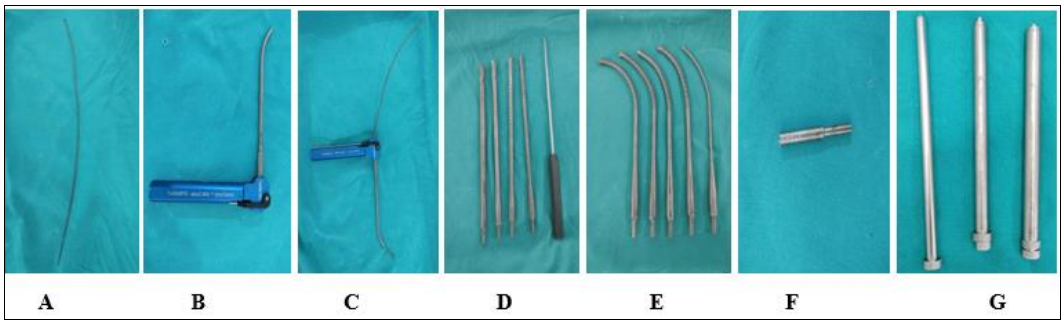


**Fig 2:** The tools for the surgery (stryker), usa). A: 2.5 mm flexible guide wire; B: ACL femoral guide C: guide with guide wire D: rigid reamers E: flexible reamers; F:6.5 mm hollow mill; G: PFN drill sleeve.

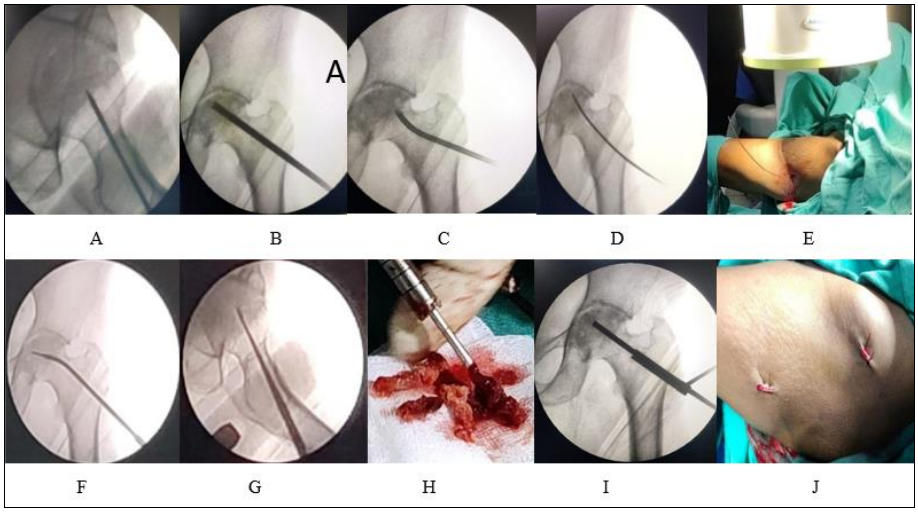


**Fig 3:** The main steps of the percutaneous core decompression and mixed bone graft technique under C-arm fluoroscopy. [A] 2.5 mm guide wire into the lesion area under image guidance [B] straight reamer 4mm; [C] The versitomic femoral acl guide in superolateral part; [D] flexible guidewire [E] 4 mm flexible reamer [F] femoral guide in inferomedial aspect of the lesion [G] residual lesion removal with a curette.[H] Autologous bone from the ipsilateral ilium with a hollow mill; [I]: Introduce the bone graft into the sleeve and punch with the blunt end of the steinmann pin.[ J] wounds closed.

## Results

A total of 23 patients and 23 hips were included in the study during the study period of 3 years (2017-2021). The average age of the study population was 43 years ranging between 32-53 years. The study included 17 males (73.9%) and six females (26%). Regarding the risk factors of AVN, 13 were idiopathic and five were steroid induced, four alcoholic and one had rheumatoid arthritis.

Mean surgical time was 50 min, and mean intraoperative bleeding was 70 ml. At 2 years follow up mean Harris hip score and VAS preoperatively were 37 and 8. After surgery mean HHS was 91 and VAS was 1. A post-operative x-ray at the latest follow-up showed that the grafted bone was basically healed.

Since 2017, we have used this new modified technique in multiple patients, and gratifying results have been obtainedcomparingson of HHS, VAS, and imaging examination before and after the operation.

## Discussion

ANFH leads to significant articular disability in young and middle aged people. It is due to osteocyte ischemia and necrosis, trabecular fracture, and femoral head collapse induced by a local blood circulation disorder of the femoral head due to various etiologies [3].Without early diagnosis and effective intervention and treatment, most of the patients need a THA after 2 years due to femoral head collapse [17,24] Current consensus is that THA is used just for advanced-stage ANFH in older patients or those who have failed joint-preserving treatment [25].Therefore, a definite and effective joint-preserving surgical treatment is urgently needed for young and middle- aged patients with early stage ANFH.

Core decompression combined with bone grafting (with or without adjuvants) as a joint-preserving surgical treatment has been widely recognized before [3, 16, 26, 27, 28]. In recent years, studies also showed that patients with ARCO classification system stage II treated by Core decompression combined with autologous bone and BMA had good outcomes [2Other studies have

already shown the usefulness of eliminating the necrotic bone and structural support by the adjuvant substances in the treatment of early ANFH ies [3, 22, 30].

Arlet and Ficat first introduced core decompression in 1964 and they reported "good to very good results" in 90% of these hips on clinical evaluation and in 79% on radiographic evaluation [31]. Marker *et al.* in his meta-analysis documented that upto 30% of hips required THR at 3 years of follow-up after core decompression [32]. Rajagopal *et al.* also reported the similar rate of conversion to THR and they pointed out that the results were better with stage 1 disease compared to other stages [33]. Core decompression was done by removing single 8-10 mm core removal to decompress the femoral head. Still, it has been documented to be associated with complications like iatrogenic subtrochanteric fracture, inadequate decompression as well as the risk of chondral injury [34, 35, 36, 37, 38]. Later, different authors documented multiple drill hole decompressions in the literature. Kim *et al.* compared multiple drilling with single core decompression and reported that statistically significant longer time for progression to collapse with multiple drilling techniques [35]. Other authors also obtained similar results with multiple drilling [36, 38].

Over the period of time, different methods have been documented in the literature to augment the results associated with core decompression. This includes use of the mesenchymal stem cells (MSC), BMPs, bone grafting, nonvascularized cortical grafts, iliac artery pedicled graft, vascularised fibular graft etc [12, 11]. MSC from adult bone marrow are multipotent and have been documented to influence the bone repair in AVNF. Early functional and radiological results associated with the use of MSC with core decompression have been reported to be encouraging even though the results of long-term follow-up are not yet available [39, 40, 41].Limitation associated with routine use of MSC is its isolation, purification and culture needs special machineries which may be available only at selected centres.

Core decompression with bone grafting has most favourable outcomes in many studies and in some could stop progression or could delay the necessity of THA in young patients.

Many people used straight reamers and superolateral part is difficult to debride with straight reamers. If multiple entry points are made to target the lesion we will compromise on the lateral cortical bone and also we will remove the healthy bone adjacent to lesion if we use reamers more than 8mm, the healthy bone scaffolding effect may reduce. More healthy bone can be retained with flexible reamers with our technique we are precisely targeting the lesion and maximum lesion can be excised and preserving as much as healthy bone in the femoral neck and head. With our technique we can address more kerboul angle.

Our new method is to use flexible Acl reamers (stryker USA) so that the lesion can be removed more precisely and thoroughly. Residual necrotic lesions are removed by cleaning with a curved curettes. We use autologous bone from the ipsilateral ilium mixed with autologous bone marrow aspirate (BMA) and backfill the bone defects in the femoral head. Sometimes we harvest graft percutaneously with help of hollow mill from ipsilateral distal femoral condyle if more graft is needed.

Ashraf. M *et al.* [42] described Micro-core decompression combined with intralesional zoledronic acid as a treatment of osteonecrosis of femoral head. They reported mean postoperative modified Harris hip score at two years in stage I, stage IIa, stage IIb and stage III which were 97.3, 91.1, 88.4 and 82.5 respectively. They found that the use of multiple micro core-decompressions with intra-lesional bisphosphonate will provide higher chances towards hip preservation especially in late cases or cases with larger lesions where percutaneous core decompression may not be successful. The author has hypothesized that a higher concentration of bisphosphonate at the pathological site can bring better results compared to systemic administration. the author did safe surgical dislocation of femoral head for micro drilling and injecting zolendronic acid.

Landgraeber *et al.* [23, 29, 30] described advanced core decompression with expandable reamer and adjuvant substances. Wei kuan Gu *et al.* [43] used percutaneous expanded core decompression and mixed bone graft technique with gratifying results. Autologous bone graft has better biomechanical and biological properties than artificial bone graft and has all the requirements for good bone remodeling in terms of osteoconduction, osteoinduction, osteogenesis as well as osteointegration [44].

However, our new technique needs to be confirmed in more cases along with more detailed data comparison and further research. In the future, the research will also include age factors, Kerboul angle [45], and the size and location of lesions on the outcomes.

## Conclusion

Technique of percutaneous core decompression with flexible reamers and percutaneous autologous iliac bone harvesting mixed with bone marrow aspirate and tricalcium phosphates is minimally invasive, simple, safe, and reliable and advantageous in terms of precise targeting lesion and bone preserving. More kerboul angle can be addressed. No serious perioperative complications were observed in our cases. The percutaneous technique of iliac bone graft harvesting is easy to obtain and less traumatic to patient.Thus, this technique is an effective joint-preserving surgical treatment for patients with early stage ANFH. It has less learning curve and inexpensive as well. We present it here in the hope that our other colleagues could perform and further demonstrate and verify its effectiveness.

## Pitfalls and future research perspectives

1. Short follow up period. 2. Did not include bilateral AVN.3.We did not do MRI and CT post operatively and during follow up due to financial constrains.

Future research should demonstrate effect of age, gender, risk factors, Modified Kerboul angle [45], the size and location of lesions on the outcomes of this technique.

Mixing with allogenic bonegraft and use of fibular strut in femoral neck and lateral cortex was not studied and may improve clinical outcomes much better than cancellous bone graft alone.

Core decompression combined with bone grafting mixed with BMA and zolendronic acid may be considered for future research.

**Conflict-of-interest statement:** The authors declare that they have no conflicts of interest.

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## References


1. Choi HR, Steinberg ME, Cheng YE. Osteonecrosis of the femoral head: diagnosis and classification systems. Curr Rev Musculoskelet Med. 2015;8:210-220. [PMID: 26088795 DOI: 10.1007/s12178-015-9278-7]
2. Mont MA, Cherian JJ, Sierra RJ, Jones LC, Lieberman JR. Nontraumatic Osteonecrosis of the Femoral Head: Where Do We Stand Today? A Ten-Year Update. J Bone Joint Surg Am. 2015;97:1604-1627. [PMID: 26446969 DOI: 10.2106/JBJS.O.00071]
3. Zalavras CG, Lieberman JR. Osteonecrosis of the femoral head: evaluation and treatment. J Am Acad Orthop Surg. 2014;22:455-464. [PMID: 24966252 DOI: 10.5435/JAAOS-22-07-455]
4. Banerjee S, Issa K, Pivec R, Kapadia BH, Khanuja HS, Mont MA. Osteonecrosis of the hip: Treatment options and outcomes. Orthop Clin North Am. 2013;44:463-476. [PMID: 24095063 DOI: 10.1016/j.ocl.2013.07.004]
5. Vardhan H, Tripathy SK, Sen RK, Aggarwal S, Goyal T. Epidemiological Profile of Femoral Head Osteonecrosis in the North Indian Population. Indian J Orthop. 2018;52(2):140-6.
6. Angeler MJ, Gianakos A, Villa J, Ni A, Lane J. Current concepts on osteonecrosis of the femoral head. World J Orthop. 2015;6:590-601.
7. 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]
8. Mont MA, Carbone JJ, Fairbank AC. Core decompression versus nonoperative management for osteonecrosis of the hip. Clin Orthop Relat Res. 1996;324:169-178. [PMID: 8595753 DOI: 10.1097/00003086-199603000-00020]
9. Qingyu Zhang, Lihua Liu, Wei Sun, Fuqiang Gao, Liming Cheng, Zirong Li. Extracorporeal shockwave therapy in osteonecrosis of femoral head: A systematic review of now available clinical evidences: Medicine. 2017;96:4(e5897).
10. Chen CH, Chang JK, Lai KA, Hou SM, Chang CH, Wang GJ. Alendronate in the prevention of collapse of the femoral head in nontraumatic osteonecrosis: a two-year multicenter, prospective, randomized, double-blind, placebo-controlled study. Arthritis Rheum. 2012;64:1572-8.
11. Peled E, Bejar J, Barak M, Orion E, Norman D. Core decompression and alendronate treatment of the osteo-necrotic rat femoral head: computer-assisted analysis. Int J Exp Pathol. 2013;94:212-6.
12. Sen RK. Management of avascular necrosis of femoral head at pre-collapse stage. Indian J Orthop. 2009;43:6-16.
13. Pierce TP, Elmallah RK, Jauregui JJ, Verna DF, Mont MA. Outcomes of total hip arthroplasty in patients with osteonecrosis of the femoral head-a current review. Curr Rev Musculoskelet Med. 2015;8:246-251. [PMID: 26045086 DOI: 10.1007/s12178-015-9283-x]
14. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007;89:780-785. [PMID: 17403800 DOI: 10.2106/JBJS.F.00222]
15. Zhao DW, Hu YC. Chinese experts' consensus on the diagnosis and treatment of osteonecrosis of the femoral head in adults. Orthop Surg. 2012;4:125-130. [PMID: 22927145 DOI:10.1111/j.1757-7861.2012.00192.x]
16. Pierce TP, Jauregui JJ, Elmallah RK, Lavernia CJ, Mont MA, Nace J. A current review of core decompression in the treatment of osteonecrosis of the femoral head. Curr Rev Musculoskelet Med. 2015;8:228-232. [PMID: 26045085 DOI: 10.1007/s12178-015-9280-0]
17. Musso ES, Mitchell SN, Schink-Ascani M, Bassett CA. Results of conservative management of osteonecrosis of the femoral head. A retrospective review. Clin Orthop Relat Res, 1986, 209-215. [PMID: 3720087]
18. Kamath AF, McGraw MH, Israelite CL. Surgical management of osteonecrosis of the femoral head in patients with sickle cell disease. World J Orthop. 2015;6:776-782. [PMID: 26601059 DOI: 10.5312/wjo.v6.i10.776]
19. Millikan PD, Karas V, Wellman SS. Treatment of osteonecrosis of the femoral head with vascularized bone grafting. Curr Rev Musculoskelet Med. 2015;8:252-259. [PMID: 26068178 DOI:10.1007/s12178-015-9285-8]
20. Kong FG, Han SH, Liu FW, Li YJ. Percutaneous core decompression combined with percutaneous coronary intervention for the treatment of femoral head necrosis in adults. Zhongguo Yiyao Zhinan. 2014;35:32-34. [DOI: 10.15912/j.cnki.gocm.2014.35.016]
21. Civinini R, De Biase P, Carulli C, Matassi F, Nistri L, Capanna R, *et al.* The use of an injectable calcium sulphate/calcium phosphate bioceramic in the treatment of osteonecrosis of the femoral head. Int Orthop. 2012;36:1583-1588. [PMID: 22426934 DOI: 10.1007/s00264-012-1525-6]
22. Classen T, Warwas S, Jäger M, Landgraeber S. Two-year follow-up after advanced core decompression. J Tissue Eng Regen Med. 2017;11:1308-1314. [PMID: 26177805 DOI: 10.1002/term.2056]
23. Landgraeber S, Theysohn JM, Classen T, Jäger M, Warwas S, Hohn HP, *et al.* Advanced core decompression, a new treatment option of avascular necrosis of the femoral head--a first follow-up. J Tissue Eng Regen Med. 2013;7:893-900. [PMID: 22489064 DOI: 10.1002/term.1481]
24. Ohzono K, Saito M, Takaoka K, Ono K, Saito S, Nishina T, *et al.* Natural history of nontraumatic avascular necrosis of the femoral head. J Bone Joint Surg Br. 1991;73:68-72. [PMID: 1991778]
25. Cohen-Rosenblum A, Cui Q. Osteonecrosis of the Femoral Head. Orthop Clin North Am. 2019;50:139-149. [PMID: 30850073 DOI: 10.1016/j.ocl.2018.10.001]
26. Hernigou P, Beaujean F. Treatment of osteonecrosis with autologous bone marrow grafting. Clin Orthop Relat Res. 2002;405:14-23. [PMID: 12461352 DOI: 10.1097/00003086-200212000-00003]
27. Houdek MT, Wyles CC, Martin JR, Sierra RJ. Stem cell treatment for avascular necrosis of the femoral head: current perspectives. Stem Cells Cloning. 2014;7:65-70. [PMID: 24744611 DOI: 10.2147/SCCAA.S36584]
28. Larson E, Jones LC, Goodman SB, Koo KH, Cui Q. Early-stage osteonecrosis of the femoral head: where are we and where are we going in year 2018? Int Orthop. 2018;42:1723-1728. [PMID: 29619500

DOI: 10.1007/s00264-018-3917-8]
29. Landgraeber S, Warwas S, Claßen T, Jäger M. Modifications to advanced Core decompression for treatment of Avascular necrosis of the femoral head. BMC Musculoskelet Disord. 2017;18:479. [PMID: 29162080 DOI: 10.1186/s12891-017-1811-y]
30. Landgraeber S, Tran TN, Claßen T, Warwas S, Theysohn J, Lazik A, *et al.* Geometric analysis of an expandable reamer for treatment of avascular necrosis of the femoral head. Arch Orthop Trauma Surg. 2015;135:1357-1362. [PMID: 26185054 DOI: 10.1007/s00402-015-2287-6]
31. Arlet J, Ficat RP. Forage-biopsie de la tete femorale dans 1'osteonecrose primitive; Observations histopathologiques portant sur huit foranes. Rev Rhum Ed Fr. 1964;31:257-64.
32. Marker DR, Seyler TM, Ulrich SD, Srivastava S, Mont MA. Do modern techniques improve core decompression outcomes for hip osteonecrosis. Clin Orthop Relat Res. 2008;466(5):1093.
33. Rajagopal M, Samora BJ, Ellis TJ. Efficacy of core decompression as treatment for osteonecrosis of the hip: a systematic review. Hip Int J Clin Exp Res Hip pathol Ther. 2012;22(5):489.
34. Mohanty SP, Singh KA, Kundangar R, Shankar V. Management of non-traumatic avascular necrosis of the femoral head: a comparative analysis of the outcome of multiple small diameter drilling and core decompression with fibular grafting. Musculoskeletal Surg. 2017;101:59-66.
35. Kim SY, Kim DH, Park IH. Multiple drilling compared with core decompression for the treatment of osteonecrosis of the femoral head. J Bone Joint Surg Br. 2004;86:149.
36. Song WS, Yoo JJ, Kim YM, Kim HJ. Results of Multiple Drilling Compared with Those of Conventional Methods of Core Decompression. Clin Orthopaedics Related Res. 2007;454:139-46.
37. Li J, Li ZL, Zhang H, Su XZ, Wang KT, Yang YM. Long-term Outcome of Multiple Small-diameter Drilling Decompression Combined with Hip Arthroscopy versus Drilling Alone for Early Avascular Necrosis of the Femoral Head. Chinese Med J. 2017;130(12):1435-40.
38. Mont MA, Hungerford DS. Non-traumatic avascular necrosis of the femoral head. J Bone Joint Surg Am. 1995;77:459-74.
39. Müller I, Vaegler M, Holzwarth C, Tzaribatchev N, Pfister SM, Schutt B, *et al.* Secretion of angiogenic proteins by human multipotent mesenchymal stromal cells and their clinical potential in the treatment of avascular osteonecrosis. Leukemia. 2008;22:2054- 61.
40. Kawate K, Yajima H, Ohgushi H, Kotobuki N, Sugimoto K, Ohmura T, *et al.* Tissue-engineered approach for the treatment of steroid-induced osteonecrosis of the femoral head: Transplantation of autologous mesenchymal stem cells cultured with beta-tricalcium phosphate ceramics and free vascularized fibula. Artif Organs. 2006;30:960-2.
41. Papakostidis C, Tosounidis TH, Jones E, Giannoudis PV. The role of "cell therapy" in osteonecrosis of the femoral head. A systematic review of the literature and meta-analysis of 7 studies. Acta Orthop. 2016;87:72-78. [PMID: 26220203
DOI: 10.3109/17453674.2015.1077418]
42. Ashraf M, *et al.* Micro-core decompression combined with intralesional zoledronic acid as a treatment of osteonecrosis of femoral head: A novel technique International Journal of Research in Orthopaedics Int J Res Orthop. 2020 Sep;6(5):914-919.
43. Lin L, Jiao Y, Luo XG, Zhang JZ, Yin HL, Ma L, *et al.* Modified technique of advanced core decompression for treatment of femoral head osteonecrosis. World J Clin Cases. 2020 Jul;8(13):2749-2757.
44. Hernigou P, Flouzat-Lachaniette CH, Delambre J, Poignard A, Allain J, Chevallier N, *et al.* Osteonecrosis repair with bone marrow cell therapies: state of the clinical art. Bone. 2015;70:102-109. [PMID: 25016964 DOI: 10.1016/j.bone.2014.04.034]
45. Krit Boontanapibul, James I Huddleston, Derek F Amanatullah, William J Maloney, Stuart B Goodman. lModified Kerboul Angle Predicts Outcome of Core Decompression With or Without Additional Cell Therapy The Journal of arthroplasty. 2021 Feb;36(9). DOI:10.1016/j.arth.2021.01.075.