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Treatment of Early Osteonecrosis of Femoral Head: A Review of Femoral Head Sparing Procedures

Mohammadhussain Mohammedsalim Lapia#, Zhefeng Chen#, Feng Liu, Sohail Ahmed, Weimin Fan*

Department of Orthopedics, the First Affiliated Hospital with Nanjing Medical University, Nanjing 210029, China

Abstract
Osteonecrosis (ON) is a complex disorder most commonly affecting the weight bearing joints, primarily the hip. To understand the choice of treatment in osteonecrosis, it is important to have knowledge about the classification of the lesions of osteonecrosis. The widely accepted classification systems for osteonecrosis are Steinberg classification, Ficat and Arlet classification and Association Research Circulation Osseous (ARCO) classification. However, considering the lack of level 1evidence and proportionately lesser prospective studies conducted, it is difficult to delineate an optimal therapeutic opinion for each stage of osteonecrosis. This review describes the summary of different femoral head sparing procedures along with their descriptions, advantages and disadvantages and their percent success rate. It can be said that femoral head sparing procedures is a decent modality to delay replacing procedures in precollapse stages. The core decompression alone has not been able to produce favorable results in all the stages of osteonecrosis. Thereby adjunctive options have been discovered, which have resulted in favorable clinical outcomes. With more rigorous prospective study, we will be able to come up with more possible favorable methods of treatment of osteonecrosis.
Keywords Biological agents, bone grafting, femoral head, implants, osteonecrosis.

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***Corresponding author** Weimin Fan **Email** fanweimin@vip.sina.com **Tel** +86 25 83718836 **Fax** +86 25 83724440
#These authors contributed equally to the work.

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Introduction

Osteonecrosis (ON) is a complex disorder, most commonly affecting the weight bearing joints, primarily the hip. In the United States, it is estimated that every year, there are about 20,000 to 30,000 new cases of osteonecrosis diagnosed and 10% of the 250000 Total Hip Arthroplasties (THA) are performed based on this diagnosis [1, 2]. There has been widespread literature on the treatment modalities of osteonecrosis, but the lack of level 1evidence in the literature makes it difficult to conclude one possible definite treatment. Treatment can be either medical or surgical, though surgical treatment is usually preferred since medical treatments are yet to give promising results. Surgical treatment of ON can be grouped into joint preserving surgeries in which the femoral head is spared and joint replacing surgeries wherein the femoral head is replaced. The necrotic segment of the femur collapses, joint replacement is the preferred option [3, 4]. However, since a large number of patients that are diagnosed with ON are young patients (20-40 years) [5], joint replacement cannot provide improved functional outcome throughout the lifetime. Hence, when possible, preserving of the joint should be considered over joint replacement. Joint preserving surgeries have provided encouraging results at short and midterm follow-up [6-8]. However, there has been no optimal treatment modality identified in the precollapse stages of osteonecrosis. The primary aim of this review is to enlist the femoral head sparing techniques that can be incorporated in young patients and in precollapse stages to delay or negate the possible need of Arthroplasty.

To understand the choice of treatment in osteonecrosis, it is important to have knowledge about the classification of the lesions of osteonecrosis. The widely accepted classification systems for osteonecrosis are Steinberg classification (Table 1), Ficat and Arlet classification (Table 2) and Association Research Circulation Osseous (ARCO) classification (Table 3).

Joint preserving treatments

Joint preserving techniques involve procedures that spare the femoral head while treating osteonecrosis. Those include core decompression, core decompression combined with bone grafts, biological agents or tantalum implants and Osteotomy.

Table 1 Steinberg Classification [9].

Stage	Description
0	None
I	Positive findings on bone scan or magnetic resonance imaging
II	Diffuse sclerotic or cystic lesions
III	Step-off in contour of subchondral bone
IV	Flattening of femoral head
V	Joint-narrowing or acetabular changes
VI	Advanced degenerative changes

Table 2 Ficat and Arlet classification [10].

Stage	Description
I	Normal
II	Diffuse sclerotic or cystic lesions
III	Subchondral fracture
IV	Femoral head collapse, osteoarthritis and acetabular changes

Table 3 Association Research Circulation Osseous (ARCO) classification [11].

Stage	Description
0	None
1	Normal findings on radiography or computed tomography; positive findings with at least one other technique
2	Sclerosis, osteolysis, focal lesions
3	Crescent sign and/or flattening of articular surface
4	Osteoarthritis. acetabular changes

Core decompression

Core decompression (CD) was one of the initial recommendations in regard to the treatment of early stage necrosis [12, 13]. It is one of the widely used procedures in pre collapse lesions and early stage osteonecrosis of the femoral head (ONFH) with the goal of decreasing the intraosseus pressure and the possible neovascularization within the femoral head and thereby relieving pain and prolonging or negating the need for total hip arthroplasty [14-17].

CD when used for the treatment of precollapse small lesions in osteonecrosis has encouraging results reported by several scholars. Israelite et al. concluded through his study that the CD had a significantly better outcome (14% required arthroplasty) in precollapse small lesions (<15% of femoral head involvement) when compared to intermediate (15-30% femoral head involvement) requiring arthroplasty in 48% cases and large lesions (>30% femoral head involvement) which required arthroplasty in 42% of the cases [7]. The minimum follow up period for this study was 2 years. Marker et al. conducted a systematic review in which he reviewed 1268 patient's that were treated using CD and reported that 70% of the hips did not require further surgical treatment and 63% of the patients had radiographic improvement [8]. But most of the patients in this study had small lesions and hence they concluded that CD was a safe procedure when elected for the treatment of early stage osteonecrosis of femoral head (ONFH). Another systematic review of Manoj et al. reported that out of 139 total cases a total of 25.8% patient's required Total Hip Arthroplasty (THA) post treatment with CD [18].

There are two reported methods for CD; large diameter trephines and small diameter drills. There are reported complications of articular cartilage damage, subchondral fracture and morbidity associated with large diameter trephine technique. Kim et al. [20] initially described the multiple small diameter core decompression technique. In the initial research presented by them using this technique had a lower collapse rate (14.3%) as compared to the rate reported with the standard trephine method [19, 20]. Small diameter CD is the more preferred alternative since it can easily reach the anterior portion of the femoral head which is the most common site of osteonecrosis. Also, it has lesser risks of the complications that are encountered during large diameter trephine technique [21].

Despite the encouraging results of CD in the treatment of early stage osteonecrosis, its role in the complete reconstruction of the femoral necrotic area is still unclear [22]. The combination of CD with a variety of techniques exhibit effective outcomes in the management of precollapse lesions of small to moderate sizes [23-25].

Bone grafting

Non-vascularized bone grafting

Nonvascularized bone grafting (NVBG) technique allows femoral head decompression along with removal of necrotic segment and placing a bone graft that would provide structural support and scaffolding to allow regeneration, repair and remodeling of the subchondral bone. Bone grafts (allogeneic bone, autogenous bone or bone substitution material) can be either impacted into the femoral head [26] or be placed as a strut. NVBG is a more invasive procedure than the CD which is useful in precollapse lesions of <2mm size or in patients where the CD has failed.

There are three techniques for performing a bone graft which was recently described by Seyler et al. [27] in his studies: 1) Phemister technique in which graft is placed along the tract of core decompression from the lateral side of the greater trochanter, 2) light bulb technique wherein the graft is placed into the femur through a cortical window at the femoral head-neck junction and 3) trap door technique wherein the graft is placed through a cartilage window created over the femoral head. Grafting through the core decompression tract was first introduced by Phemister et al. [28]. Successful clinical outcomes

were reported using this technique [29, 30]. Steinberg et al. [31] did a minimum 2 year follow up for 312 hips (208 patients) that were treated with core decompression and bone grafting, out of which 113 hips in 90 patients (36%) required hip replacement at a mean 29 months postoperatively. Since the long term results of this technique were not satisfactory and hence the use of this technique has reduced significantly thereafter. The trapdoor procedure was first presented by Judet et al. [32] who achieved remarkable clinical outcomes. Mont et al. [33] reported the efficacy of the trap door procedure in Ficat-Arlet stage III and stage IV hips (83% and 33%, respectively) which was remarkable for stage III patients with small to medium sized lesions. As the consistency of the joint cartilage is disturbed while using this technique which fails to heal postoperatively [34], the choice of this surgery should be made consciously. The light bulb technique was first reported by Rosenwasser et al. [35] in his study wherein successful clinical results were achieved in 81% of the patients at 12 years mean follow up. There was no damage to the joint cartilage using this technique.

There are certain novel approaches which are modified conventional techniques reported in recent literatures with varied success results. Mont et al. [36] reported successful clinical results in 18 of the 21 hips (86%) at a mean follow-up of 2 years in which they used a bone morphogenetic protein allograft light bulb technique. All small lesions had a successful clinical outcome, whereas only 11 of the 14 hips were successful. Lieberman et al. [37] carried a retrospective study in 15 patients who were treated with core decompression in adjunct with an alloy implant composite of allogenic, antigen-extracted, autolyzed cortical bone perfused with human bone morphogenetic protein and non-collagenous proteins. They reported successful outcomes in 14 of the 17 hips at an average of 53 months. Only one of theprecollapse hips developed collapse, whereas the other two had collapsed before the procedure. The data suggest core decompression may be more effective if combined with osteoinductive and/or angiogenic factors.

Vascularized bone grafting

The concept of vascularized bone graft (VBG) has an increasing interest among the surgeons as it combines the advantages of core decompression along with viable bone strut graft which supports the subchondral bone and enhances revascularization of the femoral head which had been deficient of blood supply for a long time. This concept was developed after reports suggested that the vascularization was not adequate followingnon-vascularized bone grafts. There areseven distinct approaches for obtaining a graft from around the hip bone:1) vascularized graft from the ilium [38]; 2) vascularized graft from the greater trochanter [39]; 3) vascularized graft from the greater trochanter along with a transverse lateral femoral circumflex branch [40]; 4) vascularized pedicled bone flap along with deep iliac circumflex vessels; 5) vascularized graft from the ilium and vascularized graft from the greater trochanter along with a transverse lateral femoral circumflex branch [41]; 6) vascularized graft from the ilium along with the deep branch of medial circumflex femoral artery or pedicled ilium periosteal flap; and 7) vascularized pedicled quadratus femoris flap [42-44].

Soucacos et al. [45] reported that VBG had excellent results in precollapse hips wherein 95% of the Steinberg stage II hips did not progress postoperatively while radiographic progression was seen in 44% of stage Steinberg Stage IV hips at a mean follow-up of 4.7 years. However, Aldridge et al. [46] reported excellent outcomes even in the post collapse hips. The overall rate of survival after grafting of a free vascularized fibular graft as reported by Aldridge et al. [46] in their study was 67.4% for the hips followed for a minimum of two years and 64.5% for those followed for a minimum of five years. The mean preoperative Harris hip score was 54.5 points, and it increased to 81 points for the patients in whom the surgery succeeded; 63% of the patients in that group had a good or excellent result [46]. Yen et al. [47] compared the efficacy of iliac and fibular grafts and reported similar clinical outcomes that the incidence of complication was more using iliac grafts.

Kim et al. [48] found that vascularized fibular grafting was associated with better clinical results (70% vs 35%) and was more effective than non-vascularized fibular grafting for the prevention of collapse of the femoral head in a matched population with a Steinberg Stage-IIC or larger osteonecrotic lesions. Tetik et al. [49] also reported similar results stating that the use of VBG had better clinical outcome than that of NVBG. Plakseychuk et al. [50] reported that the incidence of complication was significantly higher in the VBG group (26%) as compared to the NVBG group (8%). Since the long term success rate of the VBG was unknown, Yoo et al. [51] conducted a retrospective study involving 124 hips that were treated using VBG at a mean follow-up of 13.9 years, 13 of the 124 hips (11%) failed the treatment and underwent joint replacement. Patient's age, size and location of the

lesion affected the graft survival, whereas graft survival was not associated with the etiology and stages of the disease. Edward et al. [52] reviewed graft survivorship in 65 patients (Ficat-Arlet Stage I and II) for a mean follow up of 14.4 years (range 10.5-26 years) and reported 60% graft survival (39 hips) at the last follow up. The patients in which grafting had failed were converted to THA after a mean duration of 8 years. Despite of the potential results, particularly in younger patients, the extensive surgical time, donor-site morbidity, Heterotopic ossification, prolonged rehabilitation, and an increased risk of a proximal femoral fracture has limited its use in practice [53-56]. However the impact of this technique on future surgical procedures to be carried out on the hip, if needed, is debatable. Beaulé et al. [57] reported a case of a cemented hemiresurfacing procedure after a failed VBG at 2-year follow-up with satisfactory results. Keith et al. [58] carried out a study to evaluate THA after failed vascularized fibular graft and reported survival in 94.4% patients at 5 years and 85.4% patients at 10 years (using revision as failure). Revision arthroplasty was done in 4 of the 73 patients (7.4%). Only 58% of the hips had good or excellent results for Harris hip scores.

There are certain adaptations which are modified conventional techniques reported in recent literatures with varied success results. Fuchs et al. [59] reported their outcome of using a combination of intertrochanteric osteotomy and pedicled iliac bone block transfer in 33patients (44 hips) with Ficat II or III staging with a minimum follow up of 5 years (mean 13.5 years. Among those, 34% hips were converted to THA and 69% of the hips that did not fail had radiographic progression of the lesion. This technique could not restore the integrity of the hip joint and resulted in arthritis, which progressed with time and significant complications (femoral head collapse, nonunion/derotation of the osteotomy et al). Thereby the authors suggested that this technique should be only preferred in young Ficat stage II patients with good preoperative clinical function. Since there already are less technically demanding procedures which have lesser donor site morbidity and successful clinical results, the implication of this technique needs to be studied further. VBG combined with a tantalum implant has shown good results in short term follow up [60]. Hasegawa et al. [61] compared the long term survival rates at5 and 10 year follow ups of transtrochanteric rotational osteotomy (85% and 71%, respectively) with pedicled iliac bone grafting (67% vs 61%, respectively). These results may be due to a larger proportion of stage III patients in the osteotomy group.

The VBG has successful clinical outcomes, but it is technically demanding, has significant complications and has a potential impact on future surgical undertaking, the choice of this technique should be reserved to the precollapse stages of ON.

Tantalum implants

Porous tantalum implants have high porosity and osteoconductive micro-texture which enhances the bone growth. CD in adjunct with porous tantalum implants offers the advantage of providing structural support without the risk of autograft harvest or the infectious complications of bone allograft [62-64]. Veillette et al. [64] through his study of 54 ONFH patients treated with CD in adjunct to tantalum rod insertion reported an overall survival rate of 91.8% at 24 months, and 68.1% at 48 months with signs of progression seen in 16 hips (28%) and replacement in 9 hips (16%). In another prospective study evaluating survival of femoral head using tantalum implant in ONFH patients (Stage I or II), 86% of patients demonstrated survival at a minimum of 2 years follow-up (Mean: 39 months). Three of 22 had progressive pain and collapse and subsequent conversion to THA. Patients who did not require arthroplasty demonstrated good-to-excellent functional results as characterized by the Harris hip score [65]. There are some concerns when future THA would be necessary. These include the origination of metal debris, little bone ingrowth, complicated surgical technique and insufficient mechanical support of the subchondral bone at the time of conversion from a tantalum rod to THR [66]. Studies evaluating long term functional outcomes are required to assess the efficacy of this procedure.

Use of adjunctive biological agents

The idea of combining core decompression with osteogenic agents such as mesenchymal stem cells and/or osteoconductive agents such as bone morphogenic protein and to achieve a favorable clinical outcome in larger lesions is popular amongst the research scholars. It is believed that the supply of progenitor cells is deficient in patients with avascular necrosis and this deficiency needs to be corrected in order to achieve remodeling of the necrotic lesions [67]. For this reason, the scope of developing new techniques for stem cells introduction into the necrotic area to prevent subchondral fracture and subsequent collapse is on the rise.

Hernigou et al. [68] first described the technique of injecting mesenchymal cells into an area of

necrosis. His study prospectively followed 189 hips (116 patients) treated with CD and injection of concentrated autologous bone marrow mononuclear cells for a minimum of 5 years (mean, 7 years; range, 5–11 years). 6% (9/145) of the precollapse hips required conversion to THA whereas 57% (25/44) of the post collapse hips were converted to THA. The number of progenitor cells harvested from each patient varied according to etiologic factor, and the final concentration of progenitor cells had an influence on the outcome of the hips. Patients who had a greater number of progenitor cells transplanted in their hips demonstrated better survival. Patients with steroid- or alcohol related osteonecrosis received a low number of transplanted cells and had a greater risk of failure of the latest follow up than the patients with other diagnoses who received a higher number of transplanted cells (i.e., sickle cell, idiopathic); however, no threshold dose was identified. This may explain in part the influence of the etiologic factors on the outcome of the hips, which was also observed in this study. Those patients with alcohol- or steroid-related osteonecrosis often have marrow aspirates that yield fewer progenitor cells and this may affect the results of therapy. Conversely, the inferior results noted in these patients may not only reflect the dose-response relationship between progenitor cells and survival, but the poor bone quality of these subjects. In a double blinded, controlled study carried out by Gangji et al. [69] wherein they compared the clinical outcomes between core decompression alone and CD combined with bone marrow aspirate. There was a significant difference in the time to collapse between the two groups at 24 months follow-up. There was a 35% decrease in the necrotic lesion in the bone marrow aspirate group. There are three methods to graft stem cells into the necrotic lesion; Instillation of stem cells directly into the core tract (most commonly), a selective femoral arterial perfusion and catheterization of either the Medial circumflex femoral artery (MCFA) or a Lateral circumflex femoral artery (LCFA) (Since this technique requires higher surgical skills and is difficult, it is not preferred. The concentration of the stem cells instilled directly into the core tract determines the efficacy of the regeneration of the necrotic lesion (optimum effective dosage minimum necessary concentration 5 × 107 and CD 34 + 5 × 107 cells) [70,71].On the contrary, the relationship between the volume of the injected cells and volume of the necrotic lesion needs to be studied. Despite the encouraging results, there are many controversies which still need to be addressed and further studies are required to address these controversies [67-71].

Osteotomy

Regardless of the approach, the primary aim of performing an osteotomy is to reposition the necrotic lesion away from the weight bearing area of the joint and thereby relieves stress on the necrotic segment and redistributing it to the healthy bone.

There are two approaches to perform an osteotomy for ON: 1) Angular intertrochanteric osteotomy, which can be Valgus, varus, flexion, extension or a combination of the above. 2) Rotational transtrochanteric which can be either anterior or posterior [72-76]. Drescher et al. [77] reported a survival of 90% of patients at 5 years follow up using a flexion intertrochanteric osteotomy. Ficat II stage patients had the best results for which less drastic surgical alternatives are available and preferred by surgeons. Mont et al. [78] reported satisfactory clinical outcomes without the need for replacement in 28 of 37 hips (76%) at a mean follow-up of 11.5 years following intertrochanteric varus Osteotomy. The transtrochanteric rotational osteotomy (TRO) for treatment of ONFH was introduced by Sugioka [75] in 1972. Sugioka [75] reported success rate of 78% after 3-16 years. But these results have not been reproduced [72-74]. Rotational osteotomies can provide a painless, mobile, and stable hip if the depth of the necrosis is not bigger than one third of the head diameter [75]. Hisatome et al. [76] concluded through his study that even though the new weight bearing segment does not collapse, there is persistent anterior joint instability and subsequent arthritis following progressive collapse of the repositioned necrotic segment.

The rotational osteotomy has had better outcomes in the Asian population, compared to the angular osteotomy, which has successful results in US and European population. This may be due to an anatomic variation in the Asian population; specifically, the lax posterior capsule of the hip that allows better rotation of the anterior femoral neck [72].

Osteotomy is not preferred largely by the surgeons due to its low success rate, higher incidence of complications and the resultant deformities in the femur which complicate any future surgical procedures to be carried out over the femur [72-78]. Successful osteotomy is associated with the size of the lesion and amount of viable bone, which can be repositioned away from the weight bearing area. It is indicated in young patients who do not take corticosteroid medications with at least 90 degrees of hip flexion and the necrotic lesion occupies <30% of the femoral and the combined necrotic angle is less than 200.

Conclusions

Considering the lack of level 1 evidence and proportionately lesser prospective studies conducted, it is difficult to delineate an optimal therapeutic opinion for each stage of osteonecrosis. However, reviewing the widespread literature, it can be said that femoral head sparing procedures is a decent modality to delay replacing procedures in precollapse stages. Every modality has its own advantages and disadvantages. Core decompression alone has not been able to produce favorable results in all stages of osteonecrosis. Thereby adjunctive options have been discovered which have resulted in favorable clinical outcomes. With more rigorous prospective study, we will be able to come up with more possible favorable methods of treatment of osteonecrosis.

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