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Joint-preserving procedures for osteonecrosis of the femoral head

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- Osteonecrosis of the femoral head is a poorly understood condition that may lead to progressive destruction of the hip joint. Its incidence is common between the third and fifth decades of life and it is the diagnosis behind 5–18% of annually performed total hip arthroplasties (THAs) in the USA.
- Regarding the high rate of complications of THA in that age group, authors have agreed on the importance of joint-preservation techniques for this disease but techniques vary to establish a generally accepted algorithmic approach.
- Surgical head-preserving procedures, core decompression with or without graft, stem cell augmentation, or biologic adjuncts, vascularized bone grafting, and proximal femoral osteotomies have all been published on with heterogeneous results and with limited evidence to date.
- Consensus states that the prognosis of patients with osteonecrosis of the femoral head can be significantly improved with early diagnosis and timely intervention.

Keywords: avascular necrosis; core decompression; femoral head; hip; osteonecrosis; total hip arthroplasty

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Introduction

Osteonecrosis of the femoral head (ONFH) is a multifactorial and poorly understood disease predominantly encountered in patients in their third to fifth decade of life.[1] This pathology results from disruption of the subchondral blood supply to the femoral head and constitutes a reason for total hip arthroplasty (THA) in young patients.[1,2] If left undiagnosed and untreated, this disease will progress to the eventual collapse of the femoral head.[1-3] Males are three times more affected than females, and bilateral ONFH is found in up to 75% of cases.[4,5] In general, osteonecrosis is responsible for approximately 5–18% of all THA cases.[6-8] In most countries, the incidence and prevalence of avascular necrosis (AVN) are reported based on unreliable data consisting of rough estimates on the rate of osteonecrosis. Chronic alcohol consumption and steroid administration are the most common aetiologies. Asian populations are considered to be more prone to developing AVN; in China, the number of new appearances is about 75,000–150,000 per year. Nationwide surveys from Japan and Korea reported the annual prevalence at more than 10,000 cases. In Taiwan, about half of the total number of hip arthroplasties were carried out due to femoral head osteonecrosis.[9]

Patients with ONFH are typically younger and may not have as durable an outcome with standard THA.[1] Therefore, joint-preserving procedures are thought to play an important role in the management of these patients.[1,3] Diagnosis of ONFH can also be challenging. Although the disease often presents insidiously with gradual onset of hip and groin pain, it can frequently be asymptomatic, therefore suspicion is judicious for early diagnosis.[3,10] Min et al reported the natural history of ONFH in 81 asymptomatic hips with a mean follow-up of 8.3 years.[11] Eventually, 32% of the cases progressed to collapse, underlining the benefits of early diagnosis for appropriate care and treatment.[11]

Magnetic resonance imaging (MRI) is an indispensable tool for detection of the initial lesion of ONFH with 90–100% sensitivity.[12,13] Despite the lack of concrete data regarding the most optimal joint-preservation procedure, the prognosis for patients with ONFH can be significantly improved with early diagnosis and intervention.[3,14]

Many variables, such as stage of the disease, patient age, lesion size, and lesion location, play an important role in selection of the treatment choice.[2,3,7,15] While joint-preserving techniques have shown significantly improved outcomes if used in early, pre-collapsed patients,[4,15,16] THA

remains the most common technique after collapse of the femoral head.[16]

Johnson et al reported a study utilizing The Nationwide Inpatient Sample database in order to determine trends in the types and numbers of procedures performed for the treatment of osteonecrosis from 1992 to 2008 in the United States.[16] They found the most frequently reported pre-collapse procedure was core decompression whereas the most frequently reported post-collapse procedure was THA. During the time period evaluated in their survey, the total number of procedures performed increased from 3,570 to 6,400 procedures per year.[16] While joint-preserving procedures declined from 25% to 12%, joint replacement increased from 75% of procedures performed to 88%.[16] They concluded that the total increase of procedures may reflect an improved awareness regarding this disease and more aggressive approaches to diagnosis and treatment.

Recent modifications of classic techniques, as well as emerging cell engineering technologies, have led to the development of alternative strategies that may be able to improve the course of ONFH. The aim of this review is to describe the efficacy of current joint-preserving techniques and their association with different clinical presentations.

Management and treatment recommendations

In most cases of ONFH, various risk factors have synergistic action in the development of pathogenesis and they play a collaborative role in the development of eventual collapse. Among these risk factors, aetiology has a major role where corticosteroids, immunosuppressive treatment, and sickle cell disease are all associated with less favourable outcomes. The difficulty of choosing appropriate treatment in patients with these aetiologies and absence of consensus requires a comprehensive review.[17]

Joint-preserving procedures

Core decompression

Core decompression is the most widely cited and most controversial technique to reduce pain and to prevent further joint deterioration. This technique was first described by Ficat and Arlet during their attempt to obtain biopsy specimens for confirmation of the diagnosis in the pre-MRI era.[18] The original core decompression was performed by tunnelling of an 8–10 mm trephine into the necrotic lesion. The theoretical advantage of core decompression is to provide pain relief through reducing venous congestion and bone-marrow pressure.[15,19] With the decrease in intraosseous pressure, blood flow is increased to the necrotic area of bone, thus alleviating the pathologic process and promoting neovascularization (see Fig. 1).[8,13,19]

Today, clinical techniques vary widely. The overall success rate as defined by the need for further surgery has varied between 40% and 80% across multiple studies at two to seven year follow-up.[13] The best outcomes have been seen in pre-collapsed stages of the disease with small (defined as less than 15% of the femoral head or Kerboul angle < 200°), medially located lesions.[4,13,19-21]

Kim et al developed the multiple small-diameter core decompression technique with a 3.2 mm drill bit involving at least three perforations of the necrotic border.[20,22] This procedure is carried out under fluoroscopic guidance through the trochanteric ridge.[20,22] Later, Mont et al reported in 2004 that both classic large technique and the multiple-drilling technique share similar outcomes amongst other variables.[20] The multiple drilling technique is advantageous in that it lessens the complications of femoral head penetration and sub-trochanteric fractures seen in classic techniques employing larger tunnel decompression.[20,23] This multiple drilling approach also more easily targets the lesion.[23]

Reported outcomes of core decompression within the literature are controversial in many ways (see Table 1). The age of the host, the size and location of the lesion, stage of the disease, aetiology and the core decompression technique used are among the numerous variables that have yet to be fully standardized.[19,20,22,23] However, unequal follow-ups reported in the literature ranging from two to five years make it impossible to determine the validity of this technique for joint preservation. It has been shown that when applied in younger patients, on smaller size (lesions < 15% femoral head) and medially located lesions it results in better outcomes.[15,24-26]

Mesenchymal stem cells, bone-marrow implantation or growth-factor-based treatment

Osteonecrosis of the femoral head is thought to be characterized by compromised vascular supply, necrosis, and subsequent microfracturing without adequate bone remodelling and healing.[1] It has also been shown that the levels of osteoprogenitor cells in the haematopoietic and stromal marrow compartments are decreased in this disease.[27,28] The lack of sufficient osteoprogenitor cells compromises the ability of the bone to heal and remodel.[1,27-30] In order to promote improved bone healing and revascularization, new cellular-based therapies are being aimed at reversing the physiologic damage done to the bone marrow and the mesenchymal bone marrow stem cells (BMSCs).[1,4,5] Augmenting techniques such as core decompression with the addition of these cell-based therapies show promise in improving patient outcomes and slowing disease advancement.[1,19]

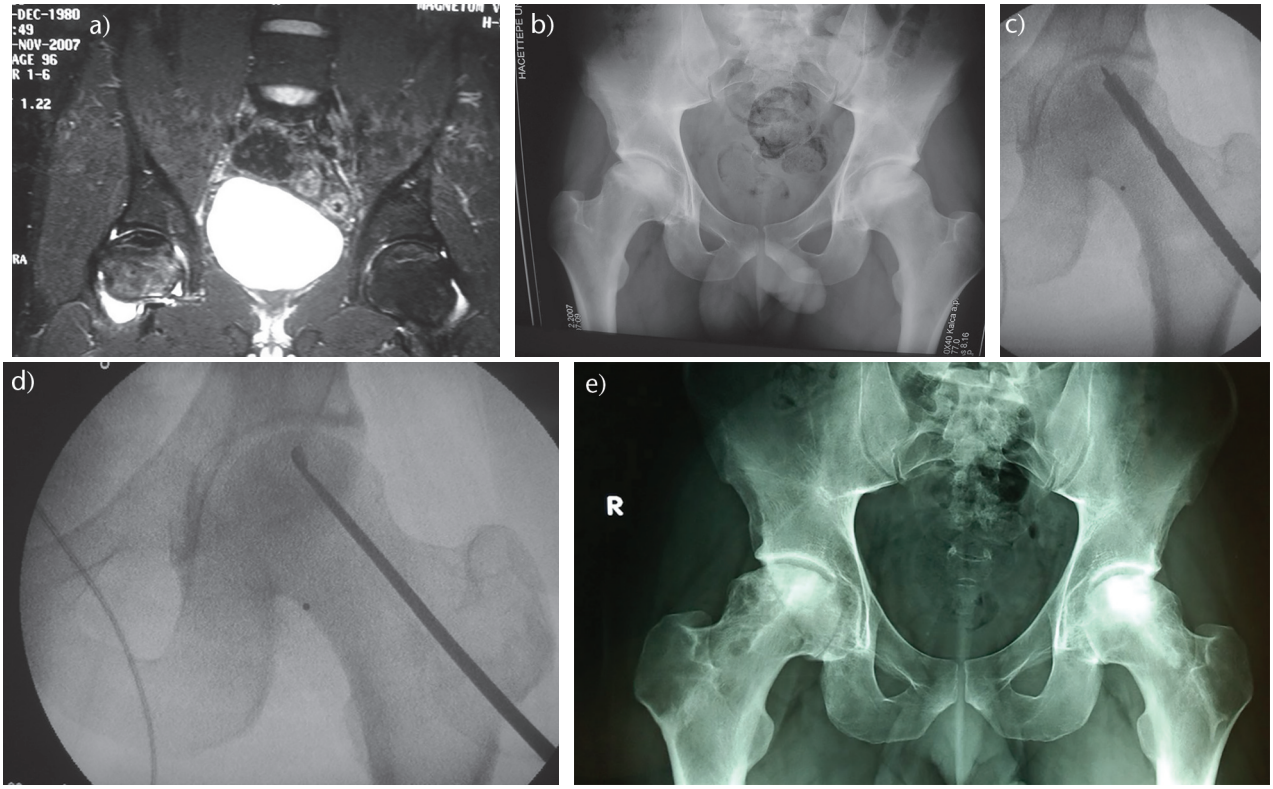

Fig. 1 (a & b) Preoperative X-ray and MRI presentation of Ficat-Arlet Stage II osteonecrosis on both hips of a 21-year-old man. **(c & d)** He was treated with classic core decompression, curettage and allograft + DBM augmentation. **(e)** X-ray demonstrates survival of both hips at 11 years follow-up with a remarkable functional outcome.

Notes. MRI, magnetic resonance imaging; DBM, demineralized bone matrix.

A prospective evaluation of 189 patients with Stage I and II hips treated with core decompression and bone-marrow transplantation, revealed that only 9 of 145 (6.2%) hips progressed to THA in seven years.[29] However, the outcome was less successful in patients presenting after collapse, with 25 of 45 (55.6%) hips requiring THA.[29]

A prospective, randomized controlled study by Gangji et al demonstrated a significantly improved time to collapse, progression of disease, and decreased hip pain and joint symptoms when comparing core decompression with autologous BMSCs versus core decompression alone.[27] Survival was defined as presence of subchondral fracture. Their analysis showed a mean survival time of 52.2 months (95% CI 43.35–60.96) in the BMSC group compared to 26.5 months (95% CI 13.20–39.75) in the core decompression group ($p = 0.008$).[27] However, they did not find a significant difference in time to arthroplasty between the two groups. A similar study by Tabatabaee et al randomized 28 patients into core decompression plus BMSC grafting and core decompression cohorts. The results of their study were similar to Gangji et al, and they found reduced pain and joint symptoms and delayed progression of disease with the addition of BMSCs.[5]

Several systematic reviews and meta-analyses have been performed in order to further examine the available data regarding cell-based therapies. Papakostidis et al performed a systematic review and meta-analysis of seven studies examining the efficacy of BMSC in addition to core decompression in osteonecrosis of the femoral head. Their meta-analysis found that core decompression with autologous BMSCs was superior to core decompression alone in regard to structural failure of the femoral head (*OR* = 0.2, 95% CI 0.08–0.60, $p = 0.02$).[31] Yuan et al additionally performed a meta-analysis of seven trials to evaluate the clinical outcomes of BMSC implantation in cases of osteonecrosis of the femoral head. They found delayed progression of osteonecrosis in the BMSC group (*OR* = 0.17, 95% CI 0.09–0.32, $p < 0.001$) and a lower incidence of total hip arthroplasty in the BMSC group compared to controls (*OR* = 0.30, 95% CI 0.12–0.72, $p < 0.01$).[32] They also found no significant heterogeneity amongst their included studies and further sensitivity analysis did not reveal any statistical difference

Table 1. Outcomes of core decompression (CD) before/after 1992 (multiple vs. classic CD)

Author	Study year	*N* (hips)	Stage	Technique	Mean follow-up	Outcome/Survival
Ficat RP[18]	1985	133	Stage I Stage II	Classic CD	10 yr	86.6% 66.7%
Stulberg BN[54]	1991	28	Stage I Stage II Stage III (Ficat)	Classic CD	2.3 yr	70.0% 71.0% 73.0%
Aaron RK[55]	1989	50	Stage I Stage II (Ficat)	Classic CD	3 yr	62.0% 25.0%
Smith SW[56]	1995	114	Stage I Stage IIa Stage IIb Stage III (Ficat)	Classic CD	3.4 yr	84.0% 47.0% 20.0% 0.0%
Fairbank AC[57]	1995	128	Stage I Stage II Stage III (Ficat)	Classic CD	11 yr	88.0% 72.0% 26.0%
Bozic KJ[58]	1999	54	Stage I-II-III (Ficat&Arlet)	Multiple Drilling	10 yr	48.0%
Mont MA[20]	2004	45	Stage I Stage II (Ficat&Arlet)	Multiple Drilling	2 yr	80.0% 57.0%
Marker BS[59]	2008	79	Stage I Stage II (Ficat)	Multiple Drilling	5.5 yr	79.0% 48.0%
Song WS[60]	2007	163	Stage I Stage II Stage III (Ficat)	Multiple Drilling	7.25 yr	79.0% 77.0% 35.0%
Kim S[22]	2004	35	N/A (all pre-collapsed)	Multiple drilling	5yr	85.7%
Scully SP[61]	1998	98	Stage II Stage III (Ficat)	Multiple drilling	50 months	65.0% 21.0%

Notes. N/A, not available; CD, core decompression.

when different studies were excluded.[32] A larger more recent systematic review by Piuzzi et al, found significant heterogeneity amongst the literature despite similarly promising results.[1] While the results are encouraging, there are some inconsistencies in the literature due to heterogeneity of the presented cases in terms of the aetiology, lesion size, and disease stage (see Table 2). Further studies utilizing large patient groups are necessary in order to elucidate not only the true effect of BMSC implantation but also the optimal source of mesenchymal stem cells. Although evidence has emerged in favour of this therapy, more evidence is needed to produce a standardized technique and recommendation.[1]

Other cellular-based techniques have been described and studied in addition to BMSC application. Specifically, bone morphogenetic protein (BMP) has been used as an addition to core decompression due to the biological molecule's ability to promote osteogenesis.[33] Lieberman et al reported on 15 patients (17 hips) treated with core decompression, fibular allograft, and 50 mg of human BMP for osteonecrosis of the femoral head.[33] All 17 hips in this retrospective study were in the early pre-collapsed stage and after follow-up only 3/17 hips showed disease progression with subsequent conversion to THA.[33] Sun et al, reported on clinical outcomes after patients were treated with impacted bone graft versus impacted bone graft with recombinant BMP (BMP-2).[34] Their findings, however, showed no statistical difference between the study arms.[34] Of a more concerning note for this technique, there has been an association between BMP and increased cancer risk, making this a less ideal method of hip preservation than other methods.[4]

Proximal femoral osteotomies

The goal of proximal femoral osteotomy in osteonecrosis is to take the necrotic lesion away from the weight-bearing area of the joint and redirect the forces to the healthy portion of the head in order to promote healing and prevent collapse.[13,23] Rotating the femoral head has a double effect of reducing the intraosseous venous pressure and promoting neovascularization with the returned blood flow.[13]

A variety of osteotomies are described in the literature including rotational transtrochanteric osteotomy (anterior and posterior) and angular intertrochanteric osteotomy (flexion, extension, varus or valgus and combined using various combinations). The success rates of rotational transtrochanteric osteotomies have been reported at 70–93% in Asian countries, with much less success being

Table 2. Outcomes of core decompression augmented with a biologic regenerative agent

Author	Study year	*N* (hips)	Stage	Technique	Mean follow-up	Outcome/Survival
Lieberman JR[33]	2004	17	Stage IIa-IIb-III (Ficat)	CD+BMP	4.5 yr	82.4%
Mont MA[62]	2007	21	N/A	CD+BMP	2 yr	86.0%
Papanagiotou M[63]	2014	7	Stage II-III (Steinberg)	CD+BMP-7	4 yr	83.0%
Gangji V[64]	2005	18	Stage I-II (ARCO)	CD+ABMMCs	2 yr	90.0%
Hernigou P[29]	2002	189	Stage I Stage II Stage III Stage IV (Steinberg)	CD+ABMMCs	7 yr	97.0% 92.0% 59.0% 37.0%
Wang B-L[65]	2010	59	Stage I Stage IIA Stage IIB Stage IIC Stage IIIA (ARCO)	CD+ABMMCs	2.3 yr	100.0% 85.7% 84.6% 71.4% 66.7%
Liu Y[66]	2013	55	Stage II (ARCO)	CD+ABMMCs	2 yr	78.6%
Zhao D[67]	2012	104	Stage I-II (ARCO)	CD+ABMMCs	5 yr	96.2%
Lim YW[68]	2013	159	Stage IIa Stage IIb Stage III (Ficat)	CD+ABMMCs	5 yr	64.3% 56.7% 42.9%

Notes. N/A, not available; CD, core decompression; BMP, bone morphogenic protein; ABMMC, autologous bone marrow mononuclear cells.

reported in European nations.[13,23] However, angular intertrochanteric techniques have reported success rates of 72–98% in the US and Europe after follow-up of 4–12 years. [23,35]

Critics of proximal femoral osteotomy have argued that higher complication rates are a result of the more technically demanding surgical procedure.[8,13,35] Complications such as fixation failure, delayed or non-unions, and difficulty obtaining an ideal position intraoperatively have been reported, and likely contribute to the lower utilization of this technique.[19] In addition, conversion to a THA is more difficult if a femoral osteotomy was previously performed due to the distortion of the proximal femur.[13,19,36]

Zhao et al, after a mean follow-up of 12.4 years (range, 5–31 years), reported that 91.8% of the hips remained intact and did not need conversion to a THA. Results are more encouraging in the presence of more than one-third of normal superolateral bone but varus osteotomy produces 2 cm of shortening on the affected limb.[35-38] Newer techniques of rotational femoral osteotomy were defined to avoid shortening of the limb, to unload the necrotic bone and to create an environment in which the weight could be dispersed and stabilized on healthy cartilage. Ishikwa et al in their 2015 article underlined the difficulty of repair in cases presenting with advance collapse and extensive necrotic lesions, and suggested high-degree posterior rotational osteotomy (HDPRO) as an alternative method.[39] In their series of 60 hips, all had extensive collapsed lesions, antero-inferior viable cartilage was transferred to weight-bearing position by a mean posterior rotation of 118.5°. Evaluation of the presenting necrotic lesion size with sequential MRI revealed 19.4–59.5% decrease in one year. The authors concluded that extensive necrotic lesions decreased in size rapidly after HDPRO in young patients. However, it is technically demanding, and this has been a significant drawback to its more general acceptance.[39]

Intertrochanteric techniques have also been reported in several case series. Maistrelli et al found promising results at two years follow-up, with 71% of treated hips having satisfactory clinical outcomes as measured by Harris Hip Scores.[40] Their final follow-up at a mean of 8.2 years demonstrated a satisfactory survival rate of 58%.[40] Two similar case series by Gallinaro and Massè, and Jacobs et al reported similar rates of success with intertrochanteric techniques. Jacobs et al demonstrated a 73% success rate at 5.3 years average follow-up, while Gallinaro and Massè reported 62.5% success at 10.2 years follow-up.[41,42]

Despite these reported success rates, high levels of evidence are not available for this technique. The majority of published literature consists of single-surgeon series, and randomized controlled trials have not been performed. A review by Chughtai et al identified only a single Level II study amongst the literature reporting on ONFH.[19] While strict selection criteria are required for osteotomies they are most successful in patients not being treated with long-term corticosteroids, age < 40 years, with a body mass index (BMI) less than 25 kg/m^2, minimal osteoarthritic changes, a postoperative intact ratio of at least 33%,

Table 3. Outcomes of osteotomies (transtrochanteric, intertrochanteric, rotational)

Author	Study year	*N* (hips)	Stage	Technique	Mean follow-up	Outcome/Survival
Jacobs MA[42]	1989	24	Stage II Stage III	Intertrochanteric (varus, valgus, flexion, extension)	5.3 yr	72.7%
Stöve J[69]	2001	83	Stage I,II,III,IV,V (Ficat&ARCO)	Intertrochanteric	7 yr	69.2%
Sakano S[70]	2004	20	Stage II-III-IV (Ficat)	Intertrochanteric ostetomies (varus)	4 yr	90.0%
Mont MA[71]	1996	37	Stage II-III (Ficat&Arlet)	Intertrochanteric osteotomies (varus, flexion, extension)	11.5 yr	75.7%
Drescher W[72]	2003	70	Stage II Stage III (Ficat)	Intertrochanteric osteotomies (varus, valgus, extension)	10.4 yr	87.0% 56.0%
Zhao G[35]	2010	73	Stage IIIA-IIIB-IV (Japanese Investigation Committee)	Transtrochanteric curved Varus osteotomy	12.4 yr	91.8%
Sugioka Y[38]	1992	295	Stage II,III,IV (Japanese Investigation Committee)	Transtrochanteric rotational osteotomy	3–16 yr	78.0%
Morita D[73]	2017	111	Stage I-II-III (ARCO)	Transtrochanteric rotational osteotomy	18.2 yr	59.0%
Miyanishi K[37]	2000	125	N/A	Transtrochanteric rotational osteotomy	13.8 yr	78.0%
Rijnen WH[74]	2005	26	Stage II-III (ARCO)	Transtrochanteric rotational osteotomy	8.7 yr	56.0%
Lee Y-K[75]	2017	65	Stage IIB-III (Ficat)	Transtrochanteric curved varus osteotomy	Minimum 5 yr	89.2%
Maistrelli G[40]	1988	102	At least Stage II (Marcus, Enneking and Massam System)	Intertrochanteric osteotomies (varus, valgus)	8.2 yr	86.5%
Atsumi T[76]	1999	46	Stage II-III-IV (Ficat)	Posterior rotational osteotomy	5 yr	70.0%
Ishikwa T[39]	2015	60	IIIA-IIIB-IV (Japanese Investigation Committee)	High-degree posterior rotational osteotomy	1 yr	MRI revealed 19.4–59.5% decrease in necrotic lesion in 1 year

and necrotic lesions with a Kerboul's angle less than 200° (see Table 3).[13,19,35,36,43]

Non-vascularized bone grafting

Non-vascularized bone grafting has typically been applied in patients classified with pre- and early collapse osteonecrosis of the femoral head.[19,44] The principle underlying this technique is to remove the necrotic bone and replace it with cancellous and cortical autografts in order to provide improved structural support for the femoral head.[44] It is also thought that the grafted bone provides inherent osteoinductive and osteoconductive properties, allowing it to aid in the healing of the damaged femoral head.[19,36] While early studies found favorable results, more recent studies have reported less success.[44] Non-vascularized bone graft is placed into the femoral head using one of three described techniques: (1) the Phemister technique, (2) articular cartilage window or trapdoor technique, and (3) a cortical window or 'lightbulb' grafting technique.[15,19,44]

The Phemister technique makes use of a core decompression tract in order to place the grafted bone in the affected region.[44,45] Despite early reports showing clinical success, such as the study by Buckley et al observing 90% successful outcomes, later studies found poor long term results.[46] Smith et al noted that after an average follow-up of 14 years, only 29% (16/56) of hips treated with the Phemister technique had a satisfactory clinical outcome.[47] Another case series reported by Nelson and Clark supported these poor clinical outcomes with the Phemister technique and also found disease progression even in Ficat Stage II hips treated with this technique.[48]

A trapdoor technique implementing a window in the articular cartilage has also been described and utilized in the literature. Trapdoor grafting, introduced in 1965, is executed from either an anterior or posterolateral approach with an open arthrotomy and safe dislocation of the femoral head.[15] Under direct visualization, a cartilage window in the femoral head over the necrotic area is created for a debridement of the osteonecrotic lesion and impaction of a bone graft (see Fig. 2).[15,45] Trapdoor grafting has shown favourable results in managing advanced femoral head osteonecrosis. Mont et al reported promising results in their case series of Ficat Stage III and IV hips, with good or excellent outcomes in 83% of their patients after an average follow-up of 56 months.[15]

Rosenwasser et al originally described the lightbulb technique as the concept of debridement of the necrotic area and bone grafting through a cortical window at the femoral head–neck junction (see Fig. 3).[44,49] This technique is similar to the trapdoor technique except that it spares the articular cartilage. Seyler et al reported a study of 39 hips treated with a lightbulb technique. They

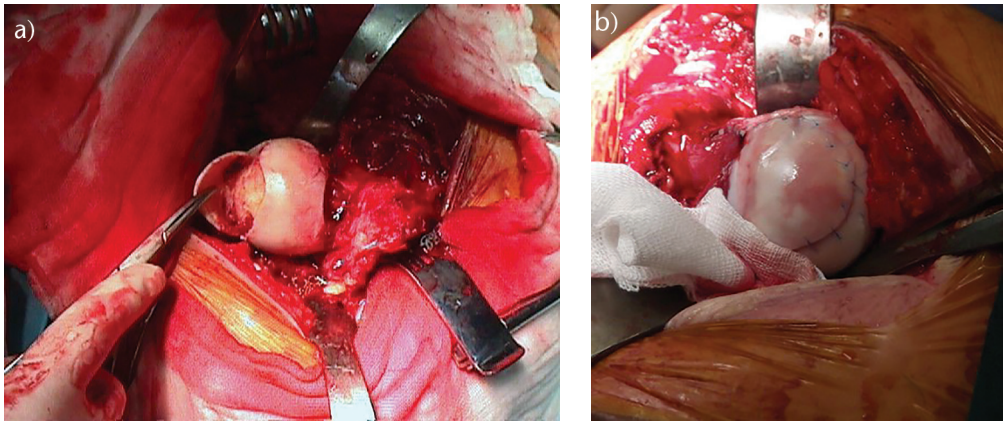

Fig. 2 **(a)** Trapdoor technique, allows for direct visualization of the necrotic lesion, curettage and grafting. **(b)** Re-suturing the cartilage flap back to its origin.

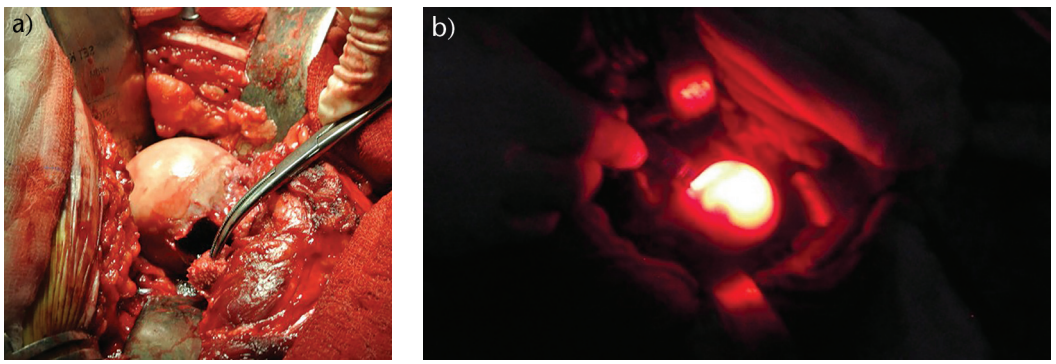

Fig. 3 **(a)** Light bulb technique is performed by hinging a cortical window on the femoral neck at the chondral junction and curettage of the necrotic lesion to the subchondral bone. **(b)** An external light source applied form the femoral neck illuminates the femoral head trough the surgical tunnel before bone graft impaction.

reported an 83% survivorship in Ficat Stage I and 78% survivorship for Stage II hips at minimum two years follow-up.[36,44] Wang et al found similar success with the lightbulb technique, reporting the patients at pre-collapse stage (IIA and B) and those presenting with smaller lesions (< 30% of the femoral head, or collapse depth < 2 mm) had significantly better prognosis (85% survival) than those at post-collapse stage (IIIC) or with large lesions (60% survival).[50]

The outcome of non-vascularized bone grafting techniques has not been evaluated by conclusive high-level studies. There is controversy over what variables affect the outcome and the most optimal technique to use. There is, however, agreement in that more successful outcomes can be expected when this joint-preservation procedure is performed in patients with small to medium sized osteonecrotic lesions (see Table 4).[13,19,36,44,45]

Vascularized bone grafting

A vascularized bone graft with its intact blood supply provides osteogenic healing potential to the necrotic lesion.[36] Like non-vascularized grafts, vascularized grafts can also be beneficial by providing structural support to the bone after the necrotic lesion is debrided.[13,36] Graft tissue is most often taken either from the iliac crest or the fibula.[13,15,36,51]. Urbaniak et al reported on 103 cases of osteonecrosis of the femoral head treated with a vascularized fibula graft. Patients with Stage II disease had a 91% survivorship rate at five years and patients with Stage III disease had a 77% survivorship rate in the same follow-up period.[51] Studies by Eward et al and Yoo et al found survivorship rates of 89% (average 13.9 years follow-up) and 75% (average 14.4 years follow-up), respectively.[52,53] An additional study by Plakseychuk et al retrospectively compared vascularized fibula grafting to non-vascularized fibula grafting and found improved clinical outcomes in the vascularized fibula graft cohort (see Table 5).[45]

Vascularized grafting is not a commonly used technique, likely due to its surgical complexity.[15,19,36,45] Operative time for a vascularized procedure is on average 210 minutes with two operative teams being involved,

Table 4. Outcomes of Lightbulb and Trapdoor technique

Author	Study year	*N* (hips)	Stage	Technique	Mean follow-up	Outcome/Survival
Gagala J[77]	2013	21	Stage IIA-IIB-IIC-III-V (ARCO)	Trapdoor	4 yr	62.0%
Ko J-Y[78]	1995	10	All collapsed	Trapdoor	4.5 yr	100.0%
Seyler TM[44]	2008	39	Stage II Stage III (Ficat&Arlet)	Trapdoor	3 yr	82.0% 47.0%
Mont MA[15]	1998	30	Stage III-IV	Trapdoor	4.8 yr	86.0%
Zhang H-J[79]	2013	85	Stage IC-IIA-IIB-IIC-IIIA-IIIB-IIIC (ARCO)	Lightbulb	Min 2 years	85.4%
Wang BL[50]	2010	138	Stage IIA-IIB-IIC-IIIA (ARCO)	Lightbulb	2.1 yr	68.0%
Yuhan Chang[80]	2009	11	Stage II-III (ARCO)	Lightbulb	5 yr	73.0%
Mont MA[81]	2003	21	Stage II-III (Ficat)	Lightbulb	4 yr	86.0%

Table 5. Outcomes of vascularised grafting for osteonecrosis

Author	Study year	*N* (hips)	Stage	Technique	Mean follow-up	Outcome/Survival
Yoo MC[53]	2008	124	Stage II Stage III (Ficat)	FVFG	13.9 yr	88.0% 91.0%
Eward WC[52]	2012	65	Stage I-II (Ficat&Arlet)	FVFG	14.4 yr	60.0%
Urbaniak JR[51]	1995	103	Stage II Stage III Stage IV Stage V (Marcus, Enneking and Massam System)	FVFG	7 yr	89.5% 77.0% 57.0% 68.0%
Sotereanos DC[82]	1997	88	Stage IC/IIA Stage IIB Stage IIIB Stage IVA Stage IVB (Steinberg)	FVFG	5.5 yr	100.0% 94.0% 80.0% 72.0% 58.0%
Gao YS[83]	2013	578	Stage II Stage III Stage IV Stage V (Steinberg)	FVFG	5 yr	96.0%
Louie BE[84]	1999	63	Stage II Stage III Stage IV Stage V (Steinberg)	FVFG	2.6 yr	100.0% 72.0% 74.0% 57.0%
Kawate K[85]	2007	73	Stage I Stage II Stage III Stage IV Stage V (Steinberg)	FVFG	7 yr	100.0% 96.9% 60.0% 76.5% 33.0%

Note. FVFG, free vascularized fibular grafting.

compared to an average of 104 minutes for a trapdoor non-vascularized bone graft technique.[15]

HemiCAP resurfacing

As a last resort for preservation of the hip in advanced stages of osteonecrosis, a HemiCAP resurfacing technique has been attempted. HemiCAP resurfacing is a bone-conserving metallic arthroplasty procedure that preserves all of the acetabulum, the viable portion of the femoral head, and the femoral neck (see Fig. 4).[19] However, the metal surface of implant is rarely well tolerated and progressive acetabular and femoral head changes make this technique unfavourable.[19] A number of case series and matched-cohort studies have shown excellent outcomes in the short to mid-term follow-up periods.[36] Despite these reported short-term findings, there is increased concern over complications such as thermal damage, periprosthetic fracture, acetabular articular cartilage damage and high rates of pain.[36] The future of the HemiCAP procedure is uncertain at this point because of the

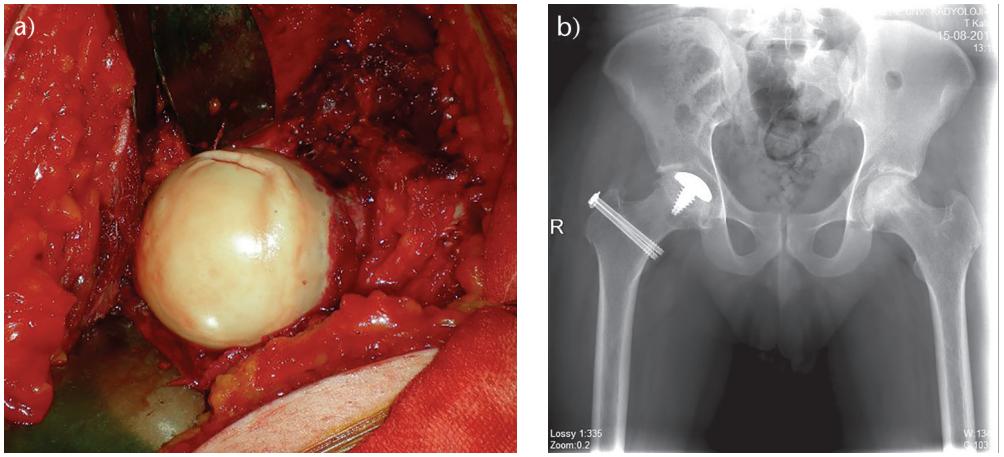

Fig. 4 **(a)** A 27-year-old man presenting with right-hip Stage III osteonecrosis with subchondral fracture. Treatment with a metal hemicap articular surface replacement. **(b)** At 10 year follow-up, the patient still has good joint function and is working as an emergency care physician.

unfavourable complications that can occur with this use of the device.[19,36]

Conclusion

Avascular necrosis of the femoral head is a serious disease encountered in younger patients that can lead to destruction of the hip joint and the need for THA. The risk of femoral head collapse even in asymptomatic patients creates potential for extreme morbidity. Early diagnosis and a high index of suspicion is crucial to obtain a favourable outcome. MRI is a sensitive and specific screening tool for establishing an early diagnosis. In general, the size and location of the lesion predicts collapse and disease progression.

The orthopaedic community has sought alternatives to THA in these young, and often active, patients. The joint-preservation procedures were introduced with the aim of avoiding or postponing the need for THA. With the favourable outcomes reported, considerations should be given to hip-preservation procedures for patients who meet the criteria for such interventions. The most optimal joint-preserving procedure remains unknown. Core decompression has been employed for decades and remains a viable option in pre-collapse osteonecrosis with small, medially located lesions. The addition of biologic regenerative agents to core decompression are particularly promising as they can introduce new cells to the area of necrosis to aid in healing and cellular repair via cytokine and growth-factor secretion.

Recent advances in managing ONFH may hold promise for patients by preventing or delaying the progression of this disease and reducing its associated clinical morbidity. In order to create evidence and be able to compare the results of various treatment modalities there is a need for a standardized classification system that offers accuracy in anticipating disease progression and selection of relevant treatment option. Additionally, more high-level studies are needed to further elucidate and validate a standardized treatment algorithm in order to better care for this patient population.

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