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REVIEW ARTICLE

The use of non-vascularized bone grafts to treat osteonecrosis of the femoral head: indications, techniques, and outcomes

Assem A. Sultan[1] · Anton Khlopas[1] · Peter Surace[1] · Linsen T. Samuel[1] · Mhamd Faour[1] · Nipun Sodhi[2] · Viktor E. Krebs[1] · Kim L. Stearns[1] · Robert M. Molloy[1] · Michael A. Mont[1,2]

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Abstract

Osteonecrosis of the femoral head (ONFH) is a multi-factorial disease with relatively unknown aetiology and unclear pathogenetic mechanism. Left untreated, the natural history of the disease is progressive collapse of the femoral head and destruction of the joint with substantial pain and disability. The disease primarily affects younger individuals, in whom many surgeons will typically prefer to delay performing total hip arthroplasty (THA). Therefore, increasing attention has been given to a wide variety of femoral head-preserving procedures. The use of non-vascularized bone grafting (NVBG) to treat ONFH has mainly been advocated for pre-collapse and select, early post-collapse lesions. Currently, multiple studies reported on various non-vascularized bone grafting techniques of treating ONFH. Clinical outcomes have varied widely, with success rates reported between 55 and 87% in the short- to mid-term, with long-term results lacking. Due to the current paucity of studies, in this review we aimed to discuss (1) indications, (2) techniques, and (3) outcomes of non-vascularized bone grafting used to treat osteonecrosis of the femoral head.

Keywords Hip oseonecrosis · Femoral head · Non-vascularized · Bone graft · Treatment · Systematic review

Introduction

Osteonecrosis of the femoral head (ONFH) is a multi-factorial disease with relatively unknown aetiology and unclear pathogenetic mechanism [1]. Left untreated, the natural history of the disease is progressive collapse of the femoral head and destruction of the joint with substantial pain and disability [2]. The disease primarily affects younger individuals, in whom many surgeons will typically prefer to delay performing total hip arthroplasty (THA), leaving this definitive option as a last resort [3]. Therefore, increasing attention has been given to a wide variety of femoral head-preserving procedures such as core-decompression, vascularized and non-vascularized bone grafting, and femoral osteotomies [4]. In each, careful patient and technique selection can be the key to success as demonstrated with multiple studies reporting different clinical success rates [5].

The use of non-vascularized bone grafting (NVBG) to treat ONFH has mainly been advocated for pre-collapse and select, early post-collapse lesions [6]. Multiple studies have shown that the success of this technique relies on providing adequate structural support following necrotic segment decompression to allow for subchondral bone remodeling and healing [7, 8]. Historically, three main techniques have been described. Phemister [9] reported the use of a cortical strut graft impacted in a cylindrical 8- to 10-mm cone through the femoral head and neck. Meyer et al., [10] performed a NVBG of the femoral head through surgical dislocation of the hip joint and a trapdoor made through the articular cartilage of the head. Rosenwasser et al., [11] described the "lightbulb" technique in which a window is made in the proximal femoral neck, allowing access to the necrotic area in the head for debridement then subsequent packing by bone graft. In all of these procedures, a variety of graft material including cancellous and cortical grafts, with or without augmentation by volume expanders, osteo-inductive, or osteo-conductive allografts have been also reported [1, 12–21].

✉ Michael A. Mont
montm@ccf.org; rhondamont@aol.com

[1] Department of Orthopaedic Surgery, Cleveland Clinic, Cleveland, OH, USA

[2] Department of Orthopaedic Surgery, Lenox Hill Hospital, New York, NY, USA

Currently, multiple studies reported on various non-vascularized bone grafting techniques for treatment of ONFH. Clinical outcomes varied widely, with success rates reported between 55 and 87% in the short- to mid-term, with long-term results lacking [1, 7, 8]. Due to the current paucity of studies, in this review we aimed to discuss (1) indications, (2) techniques, and (3) outcomes of non-vascularized bone grafting used to treat osteonecrosis of the femoral head.

Methods

Literature search

A comprehensive literature review was conducted by searching the following databases: PubMed, EMBASE, EBSCO Host, and SCOPUS. Studies published between January 1, 2000 and March 1, 2018 were reviewed. The following key words were used in combination with Boolean operators AND or OR for the literature search: "femoral head," "osteonecrosis," "avascular," "necrosis," "core decompression," "bone graft," "non-vascularized," "techniques," and "outcomes". We defined the inclusion criteria for qualifying studies for this review as follows: (1) studies that reported on indications and patient selection for NVBG, (2) studies that reported on NVBG techniques, and (3) studies that reported clinical outcomes with minimum follow-up of two years. In addition, the following exclusion criteria were applied: (1) purely technical reports, (2) case reports, (3) reports not in the English language, and (4) previous reviews. Additionally, we excluded duplicate studies among searched databases. These inclusion criteria were applied by two independent researchers: a senior board-certified orthopedic surgeon and an orthopedic surgery clinical research fellow. If disagreement was encountered, a third independent reviewer was consulted.

Data acquisition

The initial search yielded 181 reports that were screened for relevant studies. This yielded 94 reports whose abstracts were thoroughly reviewed for eligibility according to the inclusion and exclusion criteria, which in turn yielded 32 studies. Next, the full text of these 32 studies were obtained and reviewed for further analysis. All available electronic copies of the reports were collected. In the event that a report was not electronically available, a digitally scanned hard copy was requested and provided through our inter-library loan service. After thorough evaluation of the full texts, a total of 13 studies met all our criteria. The reference lists of these studies were also reviewed for any other relevant reports, which yielded an additional five reports. Therefore, a total of 18 studies were included in this analysis. These studies investigated various NVBG techniques in 1492 hips with a minimum mean follow-up of two years and maximum range of 12 years. The study selection process is summarized in Fig. 1.

Results/discussion

Indications (see Table 1)

In all of the included studies, patients had an early collapse or pre-collapse, small to medium-sized lesions. In four studies, the Steinberg classification was used, and patients had stages I to III pathology. In nine studies, the Association Research Circulation Osseous (ARCO) classification was used, and most patients had lesions graded from stages I to III pathology. In five, the Ficat classification system was used, and in four of those, patients had stages II to III lesions.

Techniques

The Phemister [9] technique was the first non-vascularized bone grafting technique described in 1949. It gained increasing popularity in the 1950s and 1960s [32, 33]. The basic concept of the technique involves removing a cone of bone, about 8 to 10 mm in diameter from the femoral head and neck through lateral approach to the proximal femur. Debridement of the necrotic bone in the head is then carried out, using a variety of tools. This is followed by insertion of a strut cortical graft to fill in the cone and provide subchondral support to the head cartilage preventing collapse. Phemister described the use of fibular strut graft but later modification also included tibial and iliac crest cortical grafts. In recent studies, augmentation by different types of allografts, autologous stem cells, and other biomaterials such as bone morphogenetic proteins was also used [14, 17, 26–29, 31, 34].

In 1983, Meyers et al. [10] described the trapdoor technique. This technique is more invasive, and was developed aiming mainly to improve the debridement and grafting access to the femoral head. Surgical dislocation of the hip joint is performed in order to completely expose the chondral surface of the femoral head. The necrotic area is then approached using thin and sharp osteotomes to remove a chondral window from the femoral head, allowing access to the necrotic region. Dead bone is removed through curettage or by using a high-speed burr. The resultant void is filled with bone graft and the chondral window is replaced and fixed using headless screws or bio-absorbable pins.

The lightbulb technique to treat ONFH was proposed by Rosenwasser [11] in 1994. The technique is in fact a modification to Ganz and Buchler's 1983 technique [35], which is essentially a salvage procedure that involved an osteotomy and accessing the dead bone in the femoral head through a cortical window in the femoral neck. Later, the technique evolved and was performed without an osteotomy. A hip

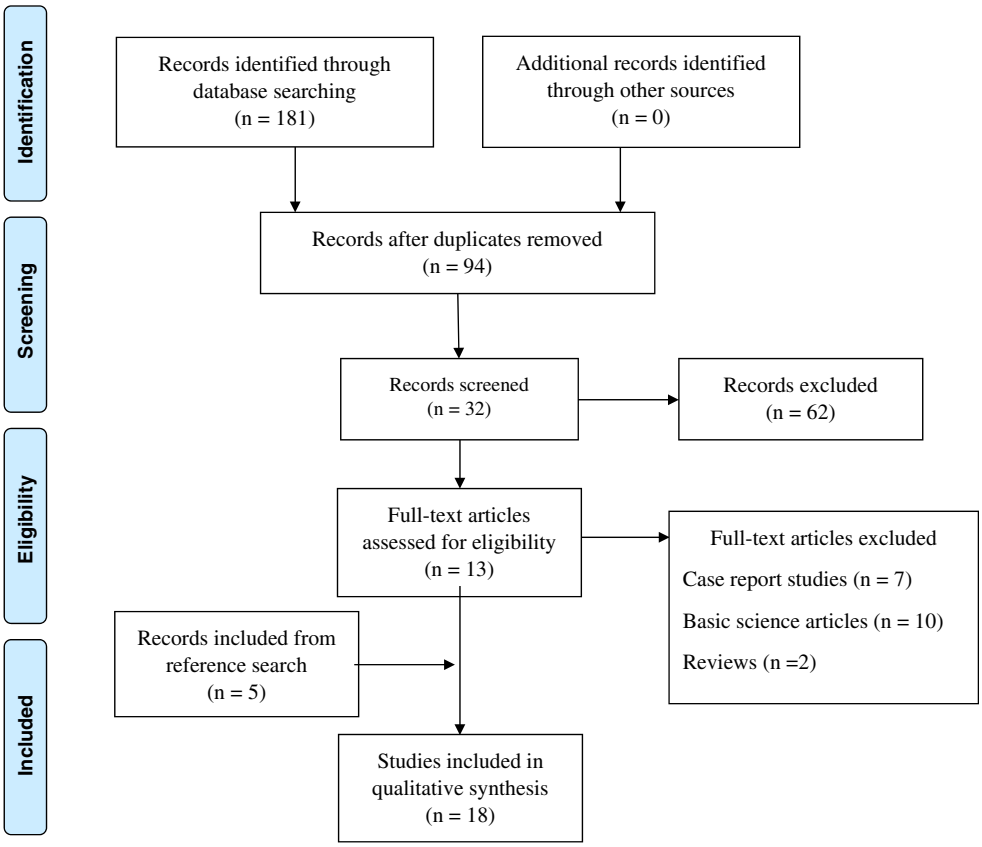

Fig. 1 Flow chart demonstrating the selection process for clinical reports in this review

arthrotomy is performed through a lateral or direct anterior approach to the femoral neck. After removal of a cortical window from the femoral neck, a high-speed burr is used to debride the head from necrotic bone. In addition, a light source can be used to visualize the corners of the void and ensure complete removal of the dead bone, marked by bleeding, healthy, cancellous bone. Next, the void can be packed by a cortico-cancellous graft or augmented as needed. The cortical window is replaced in the neck and fixed using bio-absorbable pins.

Outcomes

The Phemister technique has been used in 11 of the studies included in this analysis with varying success at final follow-up (see Table 1). Although this technique is relatively less invasive and less technically demanding compared to other techniques, it has been criticized for the inadequacy of the debridement window and the difficulty placing the bone graft in the desired location to provide support to the chondral surface of the head. In the study by Hsu et al. [27], the authors retrospectively reviewed the result of this technique to treat 31 asymptomatic and 31 symptomatic hips that had small osteonecrotic lesions with a mean follow-up of approximately four years (range, 2 to 9 years). In both cohorts, 32 to 42% of patients eventually needed a THA between 13 and 15 months following the procedure. Additionally, Keizer et al. [24], evaluated the same technique in a cohort of 78 hips and a mean follow-up of seven years. They demonstrated a mean five-year clinical survivorship of 59% that decreased to 44% at ten year follow-up. Similar results were reported by Israelite et al. In a study by Rijnen et al., the authors reported 64% successful clinical outcomes defined by minimal or no pain at mean follow-up of 42 months for a cohort of 28 hips. At final follow-up, 29% of the cohort still required a THA. The authors noted that patients who were younger than 30 years at the time of performing the procedure had more favorable outcomes compared to the elderly peers. In addition, patients with ONFH associated with corticosteroid use had the worst outcomes. The authors concluded that despite the modest results, the procedure may still be considered as an option, especially considering this less invasive procedure will not render a future THA a complex undertaking.

Few studies discussed the clinical outcomes of the trapdoor technique, and only two met this analysis' criteria. Seyler et al. [6] reviewed the results of this technique in 39 hips that had Ficat stages II and III ONFH and a mean follow-up of 3 years (range 2 to 4 years). The authors reported that 26 hips (67%) did not require conversion to THA at final follow-up and in those with Ficat stage II ($n = 22$ hips) the survivorship rate was 82%. Similarly, Gagala et al. [20] reported on the use of autologous osteochondral transfer (OATS) for ONFH through a

Table 1 Summary of the included studies

Study	Number of hips (*n*)	Technique	Stage	Mean follow-up	Hip survivorship (%)
Steinberg et al. (2001) [22]	312	Phemister	Steinberg I to IV	48 (24 to 155)	64
Rijnen et al. (2003) [23]	28	Phemister	ARCO II to IV	42 (24 to 119)	71
Mont et al. (2003) [1]	21	Lightbulb	Ficat II and III	48 (36 to 55)	86
Israelite et al. (2005) [17]	276	Phemister	Steinberg I to IV	NR (24 to 145)	62
Keizer et al. (2006) [24]	80	Phemister	Ficat I to IV	84 (– to –)	56
Seyler et al. (2008) [6]	39	Trapdoor	Ficat II to III	36 (24 to 50)	67
Yuhan et al. (2009) [25]	11	Lightbulb	ARCO II to III	61 (30 to 103)	73
Wang et al. (2010) [26]	138	Lightbulb	ARCO II to III	25.4 (7 to 42)	68
Yang et al. (2010) [12]	54	Phemister	Steinberg I to III	NR (36 to 78)	84
Tetik et al. (2011) [14]	15	Phemister	Ficat II and III	42 (16 to 114)	87
Hsu et al. (2011) [27]	62	Phemister	Steinberg I and II	46 (24 to 107)	63
Wei and Ge (2011) [28]	223	Phemister	ARCO II to III	24 (7 to 42)	81
Wang et al. (2012) [29]	28	NR	ARCO I to III	104 (93 to 108)	56
Zhang et al. (2012) [30]	85	Lightbulb	ARCO I to III	NR (24 to –)	85
Gagala et al. (2013) [20]	13	Trapdoor	ARCO II to IV	33 (18 to 75)	62
Windisch et al. (2014) [31]	18	Phemister	ARCO II and III	NR (12 to –)	78
Landgraeber et al. (2017) [19]	31	Phemister	ARCO II and III	30 (12 to 43)	76
Sionek et al. (2018) [21]	58	Phemister	Ficat II to III	4.2 years (36 to –)	81

trapdoor approach. In their cohort, 21 hips in 20 patients underwent the procedure. Seven patients had a pre-collapse, ARCO stages IIA and IIB lesions. These patients were treated with OATS alone. Additionally, 13 patients had large pre-collapse ARCO IIC and post-collapse ARCO III and IV lesions were treated with OATS and morselized bone allografts. In the first group of patients, Kaplan-Meier survivorship was 86% at four years compared to 61% in the more advanced group at three years. The authors therefore concluded that this procedure can be of benefit for patients with pre-collapse or early collapse lesions and largely aims to delay THA in these patients.

The lightbulb technique has been used in four of the included studies (see Table 1). Mont et al. [1] reported outcomes of the technique in 21 patients who had Ficat stage II or III ONFH with a mean follow-up of 48 months (range, 36 to 55 months). The authors reported that 86% of the hips (n = 18 hips) had successful clinical and radiographic outcomes and they recommended performing this procedure in pre-collapse patients with less than 2 mm of head depression. Zhang et al. [30] reviewed 67 patients who underwent the procedure through a minimally invasive modified Watson-Jones approach. Patients had between ARCO stages IC and IIIC ONFH. The authors reported a fineness rate of 85.4%. A low rate of disease progression at 14% of the cohort at two years was also reported. Radiological evaluation showed gradual decrease in the size of necrotic head when evaluated at six months, one year, and two years post-operatively.

The Phemister, trapdoor, and lightbulb techniques provide surgical options for addressing ONFH in pre- and early collapse stages. None of the studies included in this analysis directly compared these techniques and the study designs were heterogeneous, so comparing these methods' success rates directly is not plausible. However, the above studies do clearly indicate that the proper use of these techniques yields favorable outcomes in patients with early-stage ONFH, with success rates ranging from 55 to 87%. Additionally, younger patients tended to have more favourable outcomes with these hip-preserving procedures than older patients.

ONFH frequently causes hip dysfunction earlier than it would be seen with osteoarthritis, and without hip preservation techniques these patients would be facing arthroplasty at a younger age. In a recent retrospective analysis of 548 total hip arthroplasties in patients under 35 years old, Swarup et al. [36] demonstrated that patients over the age of 25 had significantly better implant survival. Additionally, a similar study by the same group [37] isolated 204 total hip arthroplasties done specifically for osteonecrosis in patients under the age of 35 with a mean follow-up of 14 years. In this analysis, the authors showed that patients under the age of 25 at the time of arthroplasty not only had worse implant survivorship, but also had poorer hip disability and osteoarthritis outcome scores (HOOS). With modern studies demonstrating the benefits to both implant survivorship and patient-reported outcomes with delayed arthroplasty in the younger population, the reproducible success rates of the above hip preservation techniques warrant serious consideration for early and pre-collapse osteonecrosis patients.

There are several limitations to this review. Most of the studies included were of lower level of evidence and several were retrospective case series. However, ONFH is a rare disease, and extensive resources would be required to compare multiple treatment options in the same subset of patients. In addition, multiple studies included in this review were conducted in different countries and therefore the results may not account for differences in patient demographics, biomaterials used, and surgical techniques, which can all be potential confounders. Nevertheless, the consistent findings across these multiple studies point to a degree of internal validity of our pooled analysis.

In summary, NVBG is an important treatment option for ONFH. Patients with early disease and no collapse of the femoral head should be chosen, in order to increase chances of success. Even with careful patient scrutiny and appropriate technique, patients are still likely to require another procedure including THA. The value of the NVBG is to delay this. Selection of preservation technique should be based on surgeon experience with the above techniques, as well as providing as minimally invasive of a procedure as possible while still addressing the patient's level of pathology. In addition, future studies with lager cohorts and direct comparison between preservation techniques would benefit the arthroplasty community. Nevertheless, in this review we aimed to present an updated reference based on the best available evidence.

Compliance with ethical standards

Conflict of interest Assem A. Sultan, MD: nothing to disclose
Anton Khlopas, MD: nothing to disclose
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Journal of Arthroplasty: editorial or governing board
Stryker: IP royalties; paid presenter or speaker
Stryker Orthopaedics: paid consultant
Kim L Stearns, MD:
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Robert M. Molloy, MD:
Stryker: paid consultant; paid presenter or speaker; research support
Zimmer: research support
Michael A Mont, MD:
AAOS: board or committee member
Abbott: paid consultant
Cymedica: paid consultant
DJ Orthopaedics: paid consultant; research support
Johnson & Johnson: paid consultant; research support
Journal of Arthroplasty: editorial or governing board
Journal of Knee Surgery: editorial or governing board
Mallinckrodt Pharmaceuticals: paid consultant
Microport: IP royalties
National Institutes of Health (NIAMS & NICHD): research support
Ongoing Care Solutions: paid consultant; research support
Orthopedics: editorial or governing board
Orthosensor: paid consultant; research support
Pacira: paid consultant
Peerwell: stock or stock options
Performance Dynamics Inc.: paid consultant
Sage: paid consultant
Stryker: IP royalties; paid consultant; research support
Surgical Techniques International: editorial or governing board
TissueGene: paid consultant; research support

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