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SYMPOSIUM: MOLECULAR AND SURGICAL ADVANCES IN OSTEONECROSIS

Nonvascularized Bone Grafting Defers Joint Arthroplasty in Hip Osteonecrosis

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Abstract A variety of nonvascularized bone grafting techniques have been proposed with varying degrees of success as treatment alternatives for osteonecrosis of the femoral head. The success of these procedures may be enhanced using ancillary growth and differentiation factors. We retrospectively reviewed 33 patients (39 hips) with osteonecrosis of the hip who had nonvascularized bone grafting procedures with supplemental OP-1. We compared the outcomes in this cohort to similar patients treated nonoperatively or with other nonvascularized bone grafting procedures. We used a trapdoor to make a window at the head-neck junction to remove necrotic bone and packed the excavated area with autogenous cancellous bone graft, marrow, and OP-1. The minimum followup was 24 months (mean, 36 months; range, 24–50 months). We performed no further surgery in 25 of 30 small- and medium-sized lesions (80%) but did in two of nine large lesions. Hips with Ficat Stage II disease were not reoperated in 18 of 22 cases during the followup periods. Our short-term results compare similarly to nonoperative treatment and other reports of nonvascularized bone grafting. With the addition of ancillary growth factors, these procedures effectively reduce donor site morbidity and may defer joint arthroplasty in selected patients.

Level of Evidence: Level IV, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

Each author certifies that he or she has no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.
Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

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Introduction

Osteonecrosis of the femoral head is a devastating disease that often leads to destruction of the hip and the need for total hip arthroplasty [32, 35]. Annual reports from various joint registries such as the Canadian Joint Replacement Registry, the Australian National Joint Replacement Registry, and the Swedish Hip Arthroplasty Register have demonstrated that the diagnosis of osteonecrosis accounts for between 2.8% to 6% of all primary total hip arthroplasties performed [1, 7, 60]. In early stages of the disease, head-preserving treatment modalities such as core decompression, osteotomy, and vascularized or nonvascularized bone grafting are often utilized to defer head-replacing options such as total hip arthroplasty [32, 35].

The rationale for the use of nonvascularized bone grafting is to remove necrotic bone and replace it with cancellous and cortical autografts that support the subchondral bone and articular cartilage of the femoral head and may stimulate bone formation [11, 43]. Three different surgical techniques have been popularized for nonvascularized bone grafting:

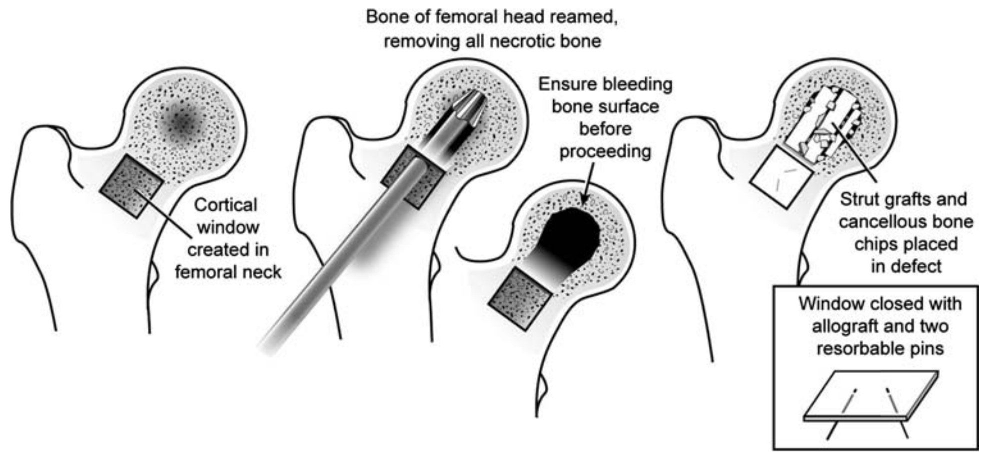

Fig. 1 The five key steps for vascularized bone grafting through a window made in the femoral neck or femoral head-neck junction are illustrated.

(1) grafting through a core decompression tract (Phemister technique) (Appendix 1 -Supplemental Website Materials; supplemental materials are available with the online version of CORR) [2–4, 24, 43, 55]; (2) grafting through a window or trapdoor in the articular cartilage (Appendix 2 - Supplemental Website Materials; supplemental materials are available with the online version of CORR) [21, 28–30]; and (3) grafting through a window made in the femoral neck or femoral head-neck junction (Fig. 1) [31, 48]. Each of these techniques has its advantages and its limitations. While earlier studies of nonvascularized bone grafting through a core tract or cartilage window reported promising clinical results [2, 6, 24, 29, 48], later studies using this technique reported less favorable outcomes [9, 39].

The use of OP-1 (BMP 7) in combination with allograft has been applied in various bone healing applications (nonunions, trauma, spine fusion) [36]. For osteonecrosis, it was used in a canine model in which defects treated with OP-1 and bone grafting healed faster radiographically than defects simply treated with bone grafting [34]. This study provided a rationale for the possible use of OP-1 in combination with allograft to heal human osteonecrotic defects.

We describe the principles, indications, and surgical techniques for nonvascularized bone grafting through a window made at the femoral head-neck junction. We asked whether this technique effectively and similarly deferred further surgical treatment options when compared to those reported in studies using nonoperative treatment. In addition, we questioned how these outcomes compared to other studies of nonvascularized bone grafting.

Materials and Methods

We retrospectively reviewed 33 patients (39 hips) with osteonecrosis of the femoral head who had nonvascularized bone grafting procedures with supplemental OP-1 performed consecutively for the appropriate indications between December 1, 2002, and January 1, 2004. Indications for the procedure were Ficat and Arlet Stage II or III lesions that met various intraoperative criteria (described later). There were 15 women (16 hips) and 18 men (23 hips) who had a mean age of 35 years (range, 18–52 years). The mean body mass index was 27.2 kg/m^2 (range, 19.4–36.0 kg/m^2). No patients were lost to followup. Minimum followup was 24 months (mean, 36 months; range, 24–50 months). After obtaining institutional review board approval, a prospective database was used to collect relevant surgical, clinical, and radiographic data.

We identified the following risk factors and associated conditions with osteonecrosis of the femoral head: corticosteroid usage (defined as a dose greater than 2 g prednisone or its equivalent per month for 3 months minimum [42]) in 9 patients (12 hips), alcohol abuse (defined as alcohol consumption of more than 400 mL per week [25]) in 8 patients (eight hips), systemic lupus erythematosus in 6 patients (seven hips), tobacco abuse (defined as 20 cigarettes or more per day [25]) in 3 patients (four hips), hepatitis C in 2 patients (three hips), and HIV infection in 2 patients (two hips). Of the remaining 4 patients (four hips), one each had an underlying diagnosis of ulcerative colitis, sickle cell disease, high levels of plasminogen activator inhibitor with hypofibrinolysis, and chronic obstructive pulmonary disease. Three patients (four hips) had no apparent associated risk factors and were deemed idiopathic osteonecrosis. Some patients had more than one associated risk factor.

We (TMS, SDU) assessed patients using the Harris hip rating system [14]. We defined failure as patients who underwent total hip arthroplasty surgery.

Anteroposterior and lateral radiographs were made preoperatively and postoperatively at 6 weeks, 3 months, 6 months, 1 year, and annually thereafter. We determined Ficat and Arlet stage [10], combined Kerboul angle [12], presence or absence of new bone formation, location of the lesion, and disease progression. Preoperative radiographs were evaluated by two of us (TMS, SDU) to determine the staging according to the system by Ficat and Arlet. The size of the lesions was measured using the combined necrotic angle technique described by Kerboul et al. [19]. The combined angle is derived from evaluating anteroposterior and lateral radiographs by adding the sums of the angle of the lesions delineated on each view. In vague cases in which the lesion was not clearly demarcated on plain radiographs, MRI and computed tomography evaluations were used to assist in the evaluation of lesion size. Using this method, the extent of the necrosis was stratified into three categories: (1) large lesions, when the combined necrotic angle was 200° or greater; (b) medium lesions, when the angle was between 150° and 200°; and (c) small lesions, when the angle was 150° or less. The location of the lesion was defined using a system initially described by Ohzono et al. [41]. Lesions were classified as type A, B, C1, or C2. A Type A lesion was one that occupied the medial third or less of the weight-bearing portion. A Type B lesion occupied the medial two-thirds or less of the weight-bearing portion. A Type C lesion occupied more than the medial two-thirds of the weight-bearing portion. The subtypes C1 and C2 were used to further stratify the C type lesions with a Type C2 lesion extending laterally to the acetabular edge, whereas a Type C1 lesion did not. Because of the possible introduction of error assessing radiographic measurements, an evaluation of interobserver and intraobserver error in radiographic assessment was performed by two of us (TMS, SDU) before reviewing study-related radiographs. The intraobserver agreement was 100% in the 10 pilot cases and the interobserver agreement was an exact match in 90% of the pilot cases. To guarantee objectivity and avoid the problem of intraobserver and interobserver variability in assessing the various radiographic parameters, two of the authors (TMS, SDU) independently evaluated the radiographs 2 weeks apart. If there was a disagreement, the senior author (MAM) interpreted the films until a unanimous decision could be made regarding the best estimate at staging, size, or extent of collapse of lesion evaluation. The various radiographic variables (Ficat and Arlet stage and Kerboul angle) were assessed to see whether they had any prognostic value. Of the 39 hips, 22 hips were classified as Ficat and Arlet Stage II and 17 hips were classified as Ficat and Arlet Stage III preoperatively. The assessment of lesions size using the Kerboul technique revealed seven small lesions, 23 medium lesions, and nine large lesions.

All procedures were performed by the senior author (MAM) using a trapdoor made at the femoral head-neck junction (Fig. 1). Large lesions were not considered a contraindication for the present patient cohort. The technique [48, 49] was performed using the anterolateral approach (Watson-Jones [62]) with the patient lying in the lateral decubitus position. The skin incision was started just distal to the anterosuperior iliac spine and carried out to a point just posterior to the greater trochanter. The incision was then angled at about 110° anteriorly and extended distally to parallel the femoral shaft for 8 to 10 cm. In the next step, the interval between the tensor fascia latae muscle and the gluteus medius muscle was identified by dividing the gluteus maximus fascia and the fascia latae. The dissection was carefully extended proximally to expose but protect the superior gluteal nerve. The fascia latae was then split in the direction of the skin incision and the anterior 40% of the gluteus medius was detached and retracted posteriorly. The gluteus minimus muscle was detached fully revealing the capsule with the head of the rectus femoris muscle attached to the upper part of acetabular rim. The capsule was then excised with the labrum left intact and the capsule peeled anteriorly to preserve the medial circumflex artery and its branches posteriorly. This approach allowed for preservation of the blood supply to the femoral head. We inspected the femoral head cartilage in situ by rotating and distracting the femur without dislocating the femoral head. The femoral head cartilage was then inspected to ascertain whether there were any full-thickness defects or areas of delaminated cartilage. We considered a defect of 1 cm or greater, cartilage delamination, or erosive areas as contraindications for performing this bone grafting procedure. This occurred in five cases during the time period of the study and these patients received a total hip arthroplasty. An approximate 2-cm × 2-cm window was then made at the femur head-neck junction (trapdoor) using a microoscillating saw and osteotomes. The window segment was preserved and stored in normal saline-wrapped gauze for replacement at the end of the procedure. A 6-mm mushroom-tipped burr was used to débride necrotic bone in the femoral head using the trapdoor as an entrance point. If 70% or more of the femoral head was involved with the disease (necrotic bone), the procedure was abandoned and a hip arthroplasty was performed. Accidental head penetration with the burr was avoided. The cavity was filled with cancellous bone chips and bone marrow. In addition, recombinant human bone morphogenetic protein 7 was added to promote new bone formation. Each sterile unit of implant contained 3.5 mg OP-1 (purchased from Stryker Biotech, Hopkinton, MA) mixed with 1 g Type I bovine bone-derived collagen. The material was tightly packed into the cavity with a layered approach and the saved bony window segment was put back and fixed with three, 2-mm poly-p-dioxanone resorbable pins (Orthosorb®, Johnson and Johnson, New Brunswick, NJ). Finally, the hip was relocated, and the gluteus minimus muscle was reattached to bone and the gluteus medius muscle and fascia latae were repaired with interrupted sutures. The procedure had a mean operative time of 62 minutes (range, 37–102 minutes).

All patients were maintained at toe-touch weightbearing with two crutches or a walker for 5 to 6 weeks. For the next 5 to 6 weeks, patients were advanced to approximately 50% weightbearing using a cane or crutch in the opposite hand. Patients were then advised to start full weightbearing as tolerated at 10 weeks postoperatively. Participation in sports and higher impact loading activities such as running were not recommended for the first 10 months postoperatively.

Survival was defined by whether the patient had subsequent surgery on the hip.

To assess how the results of the procedures for our cohort compared other nonvascularized bone grafting procedures in similarly aged patients at a similar length of followup, the authors carried out an extensive literature review of the databases of the National Library of Medicine, the National Institutes of Health, and EMBASE. We identified all articles concerning nonvascularized bone grafting for osteonecrosis of the femoral head. The key words used in the search were "hip," "femoral head," "osteonecrosis," "avascular necrosis," and "necrosis." The initial search was refined with the addition of the keywords "core decompression," "bone grafting," "nonvascularized," "trapdoor," and "lightbulb" [49]. All articles identified in this manner were then subject to a review by two of us (TMS, DRM, MAM, or TF). The search revealed 26 published studies. A similar review was conducted to identify reports of nonoperative treatment for osteonecrosis of the head. This search revealed 11 reports. For both the nonoperative and nonvascularized bone grafting literature reviews we collected the following data: failure rates (in terms of later receiving a total hip arthroplasty), surgical technique, bone grafting procedure, and demographic variables.

Results

Overall, 26 of the hips survived out of the 39 hips treated (67%). At most recent followup, 24 of the 30 hips (80%) with small- or medium-sized lesions had avoided further surgery. Patients with large lesions fared poorly with only two of nine hips avoiding further surgery. When stratified by Ficat and Arlet stage, 18 of the 22 hips with Stage II disease did not undergo further surgery. Stage III hips were less successful with only eight of 17 hips surviving. There were similar results when analyzing location of lesion, with more lateral lesions faring more poorly than centrally located lesions (Table 1). Failures ($n = 13$) had a mean time to femoral head collapse of 13 months (range, 2–34 months) (Table 2).

Table 1. Correlation between lesion size, location, Ficat and Arlet stage, and incidence of collapse

	Number of hips	Number collapsed	Incidence of collapse
Lesion Size			
Small	7	1	13%
Medium	23	5	17%
Large	9	7	78%
Location of Lesion			
A	8	1	13%
B	12	5	42%
C1	12	2	17%
C2	7	5	71%
Ficat and Arlet Stage			
Stage I	0	NA	NA
Stage II	22	4	18%
Stage III	17	9	53%
Stage IV	0	NA	NA

NA = not applicable.

The mean preoperative Harris hip scores for all patients in this series was 50 points (range, 28–76 points). The preoperative scores for the hips that subsequently failed (mean, 47 points; range, 28–72 points) were similar ($p = 0.175$) to those of the survival group (mean, 52 points; range, 28–76 points). At a mean followup of 35 months, the mean postoperative score for the entire series improved to 75 points (range, 27–100 points) ($p < 0.001$). There were no perioperative complications documented.

Medically, one patient had a urinary tract infection which resolved without any sequelae. There were no other medical complications.

The overall early clinical success (defined as not later undergoing total hip arthroplasty) rate of 67% (26 of 39 hips) for this procedure as well as the 80% (24 of 30 hips) success rate for small and medium sized lesions compared similarly to other nonvascularized procedures performed at similar mean followup (range, 28–144 months) (Table 3). We have also provided results of nonoperative studies for comparison (Table 4).

Discussion

Nonvascularized bone grafting techniques for the treatment of osteonecrosis of the femoral head were popularized in the 1950s and 1960s [3, 4, 43]. The literature reports a wide range of success rates with these techniques and this may be a result of the various surgical techniques and/or reflect the problem of choosing the appropriate treatment modality for the various disease stages. We evaluated our recent

Table 2. Characteristics of clinical failures

t	Age	Gender	Risk factors	Ficat and Arlet stage	Lesion size (Kerboul)	Location of lesion	Time to failure (months)
1	36	Male	hyperlipidemia, smoking	II	Medium	B	16
2	22	Male	alcohol	III	Large	B	31
3	51	Female	SLE, corticosteroids	III	Large	C1	12
4	27	Female	SLE, corticosteroids	II	Medium	B	8
5	37	Male	HIV, hepatitis C	III	Large	C2	6
6	30	Female	SLE, corticosteroids	II	Small	B	34
7	36	Male	alcohol, smoking	III	Large	C2	2
8	44	Female	SLE, corticosteroids	III	Large	B	16
9	52	Male	HIV, hepatitis C	III	Large	C2	8
10	31	Female	SLE, corticosteroids	II	Medium	A	24
11	55	Female	SLE, corticosteroids	II	Medium	C2	10
12	29	Female	alcohol, smoking	III	Large	C1	7
13	41	Male	corticosteroids	II	Medium	C2	9

SLE = systemic lupus erythematosus.

experience with nonvascularized bone grafting. The primary questions were whether this technique effectively deferred further surgical treatment when compared to those reported in studies using nonoperative treatment. In addition, we questioned whether the outcomes in this study were comparable to other studies of nonvascularized bone grafts.

Our study has several shortcomings including the small number of patients and the short-term followup. Nevertheless, the early results encourage the continued use and further study of this procedure. A larger series with longer followup will further help assess positive and negative predictors of outcome.

Several authors have described results comparable to ours using variations of these nonvascularized bone grafting procedures. Saito et al. [51] reported various treatment modalities for idiopathic necrosis of the femoral head. Their series included 18 hips with Ficat and Arlet Stage II osteonecrosis treated with a similar technique of nonvascularized bone grafting using cancellous bone obtained from the ipsilateral iliac crest. At a minimum followup of 24 months (mean, 48 months; range, 24–144 months), the clinical evaluation revealed Merle D'Aubigné [27] scores of 15 or more points in 13 of 18 hips. However, radiographic results demonstrated less favorable results, with seven of the 18 hips showing progressive femoral head collapse. We included both Ficat and Arlet Stage II and III hips, which may have contributed to the slightly lower chance of having a Harris hip score above 70.

The percentage of hips in our cohort of patients with nonvascularized bone grafting patients whom we considered had success treatment (67%) was similar to that in other reports in the literature (Table 3). The clinical success of the lightbulb technique ranged from 68% to 87% compared to a range of 36% to 90% reports for the Phemister technique. Similarly, the clinical success of the trapdoor technique ranged from 71% to 89%.

The proportion of nonvascularized bone grafting patients in our cohort who underwent total hip replacement (67%) was lower than six of the 11 studies that reported the outcomes of patients who were treated nonoperatively. The success (defined as not having total hip replacement by final followup) in studies from 1986 to 2007 of nonoperative treatment ranged from 9% to 86% (Table 4).

Other authors combined this technique with intertrochanteric osteotomy, use of growth factors, or gluteus medius muscle pedicle bone graft [31, 48, 52]. Scher and Jakim [52] prospectively studied 45 hips with Ficat and Arlet Stage III osteonecrosis treated with intertrochanteric osteotomy and nonvascularized bone grafting through a window in the femoral neck. The 5-year survival rate was 87%. This encouraging survival rate, however, should be critically evaluated because of the stringent inclusion criteria that were employed. The study included only patients younger than 45 years of age, with Ficat and Arlet Stage III of the anterosuperior part of the femoral head, with no underlying metabolic bone disease or systemic condition treated with chemotherapy or corticosteroids, and with no extensive involvement of the posterior part of the femoral head. Rosenwasser et al. [48] reported the long-term results of their series using the lightbulb technique. At a minimum followup of 120 months (mean, 144 months; range, 120–180 months), the survival rate was 87% with minimal disease progression. In three patients, the authors used a gluteus medius muscle pedicle graft to augment blood supply to the femoral neck. Mont et al. [31] reported on a

Table 3. Literature review of nonvascularized bone grafting techniques

Study	Year	Hips	Followup (months)	Clinical success (%)	Radiographic success (%)
Trapdoor technique					
Meyers et al. [29]	1983	21	NA	71	NA
Meyers et al. [29]	1991	9	35 (12–107)	89	NA
Ko et al.* [21]	1995	14	53 (24–108)	85	70
Mont et al. [33]	1998	30	56 (30–60)	73	73
Phemister technique					
Bonfiglio and Voke [4]	1968	116	67 (24–204)	78	NA
Boettcher et al. [2]	1970	38	72 (24–204)	79	76
Marcus et al. [24]	1973	11	N/A (24–48)	90	91
Dunn and Grow [9]	1977	23	40 (27–98)	74	30
McBeath and Oeljen [26]	1977	6	NA	83	0
Smith et al. [55]	1980	56	144 (24–332)	57	NA
Steinberg et al. [57]	1984	19	> 6	82	36
Buckley et al. [6]	1991	20	96 (24–228)	90	90
Nelson and Clark [39]	1993	52	NA (24–144)	77	13
Steinberg et al. [58]	2001	312	63 (23–146)	64	61
Mont et al. [31]	2003	21	48 (36–55)	86	76
Plakseychuk et al. [45]	2003	50	60 (36–96)	36	28
Rijnen et al. [46]	2003	28	50 (24–119)	71	57
Lieberman et al. [23]	2004	17	53 (26–94)	82	82
Kim et al. [20]	2005	30	50 (36–67)	78	80
Israelite et al. [16]	2005	276	N/A (24–145)	62	NA
Wang et al. [61]	2005	28	26 (24–39)	68	64
Keizer et al. [18]	2006	80	84 (36–NA)	46	43
Lightbulb technique					
Saito et al. [51]	1988	18	48 (24–168)	72	61
Scher and Jakim* [53]	1993	45	65 (36–126)	87	71
Rosenwasser et al. [48]	1994	15	138 (108–180)	86	86
Mont et al. [31]	2003	21	48 (36–55)	86	NA
Our study	2007	47	28 (12–50)	68	64

NA = data not available; *combined with osteotomy.

Table 4. Literature review of nonoperative treatment outcomes

Musso et al./1986 [38]	50	30	32
Steinberg et al./1989 [56]	55	21 (6–120)	16
Churchill and Spencer/1991 [8]	18	60	50
Stulberg et al./1991 [59]	22	27	9
Robinson and Springer/1992 [47]	16	39 (24–61)	56
Bradway and Morrey/1993 [5]	15	23 (3–66)	13
Jergesen and Khan/1997 [17]	19	111 (51–81)	42
Lai et al./2005 [22]	25	24	32
Hernigou et al./2006 [15]	121	168 (120–240)	25
Neumayr et al./2006 [40]	21	36	86
Morse et al./2007 [37]	67	23 (17–31)	70

*Defined as not requiring conversion to total hip arthroplasty by final followup.

series of 19 patients (21 hips) treated with bone morphogenetic protein-enriched allograft to avoid donor site morbidity. At a minimum followup of 36 months (mean, 48 months; range, 36–55 months), three hips had failed the bone grafting procedure. Interestingly, all failures occurred in hips with large-sized lesions, suggesting lesion size was associated with failure.

Despite the limitations of the study, we are encouraged by these early results using cancellous bone chips, bone marrow, and bone morphogenetic protein-7 as a nonvascularized bone grafting technique for the treatment of Stage II and III osteonecrosis of the femoral head. The decreased progression of symptoms at a mean of 36 months suggests the natural progression of the disease and subsequent hip arthroplasty surgery has been delayed. This technique is straightforward, has low donor site morbidity, and demonstrates a high degree of efficacy for Stage II and small to medium sized lesions.

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