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SYMPOSIUM: MOLECULAR AND SURGICAL ADVANCES IN OSTEONECROSIS

Do Modern Techniques Improve Core Decompression Outcomes for Hip Osteonecrosis?

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Abstract Core decompression procedures have been used in osteonecrosis of the femoral head to attempt to delay the joint destruction that may necessitate hip arthroplasty. The efficacy of core decompressions has been variable with many variations of technique described. To determine whether the efficacy of this procedure has improved during the last 15 years using modern techniques, we compared recently reported radiographic and clinical success rates to results of surgeries performed before 1992. Additionally, we evaluated the outcomes of our cohort of 52 patients (79 hips) who were treated with multiple small-diameter drillings. There was a decrease in the proportion of patients undergoing additional surgeries and an increase in radiographic success when comparing pre-1992 results to patients treated in the last 15 years. However, there were fewer Stage III hips in the more recent reports, suggesting that patient selection was an important reason for this improvement. The results of the small-diameter drilling cohort were similar to other recent reports. Patients who had small lesions and were Ficat Stage I had the best results with 79% showing no radiographic progression. Our study confirms core decompression is a safe and effective procedure for treating early stage femoral head osteonecrosis.
Level of Evidence: Level IV, therapeutic study (see the Guidelines for Authors for a complete description of levels of evidence).

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Introduction

Various techniques for performing core decompression have been used to save the osteonecrotic femoral head. There is also considerable disagreement as to the degree of efficacy of this procedure, how it might help, and the level of influence of various patient factors (such as a history of alcohol abuse or smoking, corticosteroid use, as well as underlying diagnoses such as systemic lupus erythematosus or sickle cell anemia) and radiographic lesion characterizations (such as presence or degree of collapse, lesion size or location).

The technique of performing core decompression has varied in terms of surgical approaches, number of drillings, and the diameter of the trephines. A number of authors have advocated the use of small-diameter percutaneous drilling and believe that it as effective as large-diameter core decompression procedures [56, 73, 95]. Some authors have supplemented core decompression with electrical stimulation [79] or growth and differentiation factors [19, 24, 82]. Other studies have reported adjunctive vascularized [96] and/or nonvascularized bone grafting [35, 63]. Vascularized fibular grafting is essentially a large core decompression procedure with the introduction of a vascularized fibula, ilium, or trochanteric bone on a more local pedicle. While vascularized and nonvascularized long cortical strut bone grafting approaches could be considered variations of core decompression procedures, we believe these procedures are sufficiently different that they should be considered as alternate approaches, rather than variations of core decompression and will not be considered in this study.

The primary question we asked was whether the efficacy of core decompression, measured in terms of decreased proportion of patients having additional surgeries or showing radiographic progression to collapse, has improved during the last 15 years using modern techniques. Using these same measures of efficacy, we also asked whether modern core decompression techniques provide better outcomes than those reported in studies using non-operative treatment. Secondary questions were: (1) whether the clinical and radiographic outcomes of hip osteonecrosis patients who were treated using a recently developed small-diameter drilling core decompression technique were similar to other modern studies; and (2) whether patients who had less radiographic progression and smaller lesion sizes at the time of treatment using small-diameter drilling would be less likely to have poor outcomes with subsequent collapse and the need for additional more invasive surgeries.

Materials and Methods

We systematically reviewed the literature on the Medline and EMBASE bibliographic databases that were related to core decompression and osteonecrosis of the hip. The initial search parameters used to identify potentially relevant articles were "necrosis and hip and decompression." We then searched bibliographies of review articles for any additional relevant studies. Two of us (DRM, TMS) screened all articles according to a previously defined protocol [94]. The following inclusion/exclusion criteria were used: (1) The report provided radiographic outcomes and/or indicated whether patients underwent additional surgeries following an initial core decompression for the treatment of osteonecrosis of the hip; (2) We excluded reports that did not provide sufficient data to analyze outcomes or involved fewer than 10 patients, for example a report of a single patient treated with a powered core decompression [50]; (3) Only the most recent studies were included for patient cohorts reported at multiple times at different followups; (4) Although some reports included patients who were younger than 18 years old, we excluded studies that focused only on adolescent patients [84]; (5) We did not include reports that used long cortical strut bone grafting or vascularized bone grafting. We did include studies that reported the use of ancillary cancellous bone grafting such as the technique reported by Steinberg et al. [82]; (6) Studies with a mean followup of less than 18 months were excluded (see below for this exclusion rationale) [10, 40, 44, 65, 91]; (7) We also included the previously unpublished results of patients at our institution that were treated using a small-diameter drilling technique.

The criteria, which required a minimum mean 18-month followup for study inclusion, were used because it was believed unreasonable to consider shorter term followups when trying to assess efficacy and "failure" of these procedures. Eighteen months was utilized as approximately one standard deviation above the mean time to collapse of multiple studies (11 months). It can be difficult to determine the exact time to femoral head collapse, which may predict when a patient needs a hip replacement. This could occur fairly soon or months after head collapse when the patients' hips become more symptomatic. An example of a study with data for mean time to collapse was from our patients who had percutaneous drilling. In this study patients had a mean time to detected femoral head collapse of 11 months which led to needing a total hip replacement at a mean of 14 months. For the purpose of this report, we used the mean of 11 months plus one standard deviation (6.9 months) to determine the previously noted minimum mean followup of 18 months for the studies in our literature review.

We made an attempt to stratify all studies that met our inclusion/exclusion criteria into two groups according to when the reported procedures were performed: before 1992, and from 1992 to 2007. When the dates of surgery were not specifically noted in the study, the followup and year the study was published were used to estimate the period in which the surgeries were performed. Some studies reported procedures both before and after 1992. For these studies, attempts were made to subgroup each patient according to when the procedure was performed. However, because it was impossible to stratify the patients for some reports, we categorized these studies by when the majority of the patients were treated. There were five studies classified as pre-1992 based on these criteria [7, 52, 54, 70, 82].

For each report included in this study, the level of evidence was determined using the Clinical Orthopaedics and Related Research guidelines [14]. The demographic data fields analyzed included: etiology/associated risk factors, age, followup, and preoperative stage of the disease as defined by Ficat [18]. The outcome parameters collected for each report were the number and percentage of additional surgeries and radiographic failures. Additional surgeries were only included if they were directly related to progression of the osteonecrosis. For example, if a patient had an evacuation of a hematoma it would not have been included as a case that underwent additional surgery. Due to the variability in the modalities used in the studies to assess radiographic outcomes (Fig. 1), progression to collapse or advancement after collapse was defined as radiographic failure for this study (Table 1). Radiographic

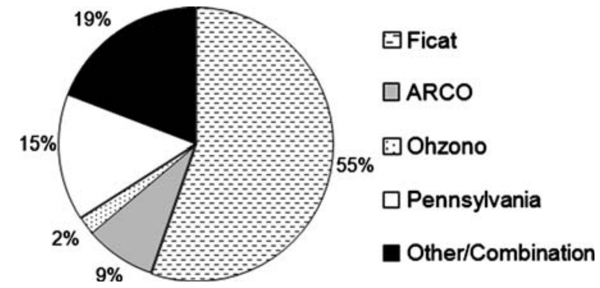

Fig. 1 The Ficat and Arlet system [18] has historically been the most frequently used staging modality. However, as noted in this graph, a large percentage of recent core decompression studies have reported using various other radiographic staging systems such as the Pennsylvania [81], ARCO [55], and Ohzono classifications [60].

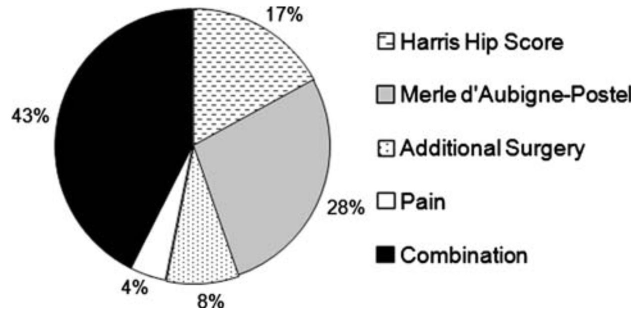

Fig. 2 This figure provides the percentage of studies that used various clinical assessment modalities. The Harris hip score [22] and the Merle d'Aubigné-Postel scale [49] were the two most common evaluation methods used to assess clinical outcomes.

outcomes were excluded for studies that did not indicate whether radiographic progression was to collapse [15, 41, 42, 70, 71] or if success was defined only in terms of a combination of radiographic and clinical failure without stratification [88, 97]. An attempt was made to also compare reported clinical outcomes. However, it was determined that the question of whether there were any differences was unanswerable using the literature given the variability and the inconsistency in clinical evaluation criteria used by the studies (Fig. 2).

We identified 47 studies that reported on the outcome of core decompression in hip osteonecrosis and met our inclusion criteria. Approximately half (25 of 47, 53%) of these reports were Level of Evidence IV, and 6% (n = 3) were conducted at Level I (Fig. 3). Alcohol abuse and corticosteroid usage were the most frequently cited risk factors (Fig. 4). Overall, there were 2,605 hips treated with core decompression. From studies reporting relevant demographic data, the mean age for patients was 39 years (range, 12–83 years), and the minimum followup was 1 month (mean, 64 months; range, 1–216 months).

While we do not consider withholding surgery an appropriate option based on previous studies showing outcomes that are less efficacious than interventional procedures used at our institution [51], we recognize that some

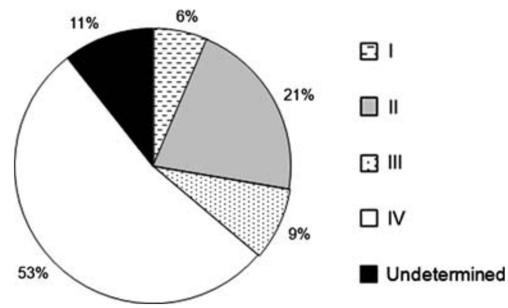

Fig. 3 The studies reviewed in our meta-analysis were grouped according to their levels of evidence [14], and the proportion of studies for each level is presented in this chart. There have been relatively few randomized, prospective studies concerning osteonecrosis of the hip, and the majority of the reports have been level of evidence IV.

physicians continue to utilize nonoperative treatment methods. To compare the results of core decompression to a baseline of natural progression, we conducted a separate literature search using the same criteria to identify a group of patients who were treated by nonoperative measures. Because the purpose of this review was to assess natural

Table 1. Criteria for assessing effectiveness of core decompressions

Measure	Inclusion/exclusion criteria	Examples
Additional surgery	1. Include additional surgeries associated with progression of osteonecrosis.	Total hip arthroplasty, vascularized bone grafting, osteotomy
	2. Exclude surgeries not directly related to long-term failure of core decompression.	Evacuation of a hematoma
Radiographic failure	1. Include progression to collapse.	Progression from Ficat II to III.
	2. Include progression from collapse to further stage of degeneration.	Progression from Steinberg IV to V.
	3. Exclude progression without collapse.†	Progression from ARCO I to II.

† Studies that only indicated "progression" in stage without indicating whether the progression was to collapse were excluded from our analysis.

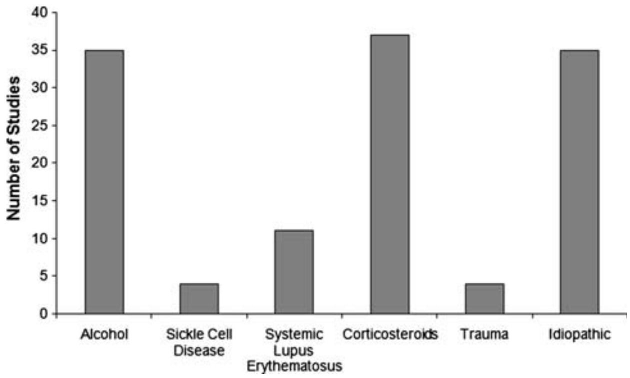

Fig. 4 The most frequently reported etiology/risk factors are listed and the number of studies in our meta-analysis that reported the outcomes of patients who were diagnosed with each of these factors is noted.

progression, we excluded nonoperative treatment modalities using external electrical therapy, ultrasound therapy, or pharmacological agents [39, 78, 90]. The mean age for these studies was 38 years (range, 13–79 years) and the minimum followup was 3 months (mean, 54 months; range, 3–240 months). The same outcome data was collected for these studies as for the review of core decompression reports.

From our institution, we identified 52 consecutive patients (79 hips) who had a core decompression utilizing a multiple small-diameter drilling (3.2–3.4 mm) technique with a minimum followup of 36 months (mean, 65 months; range, 36–81 months). The surgical technique used for these patients and the initial short-term followup of the first 45 hips was previously reported [56]. The most common risk factors in this cohort of patients were corticosteroids (n = 47 hips), tobacco abuse (n = 26 hips), and systemic lupus erythematosus (n = 20 hips) with some hips having multiple risk factors. Patients were assessed preoperatively and at final followup using the Harris hip score [22] and the Ficat and Arlet staging system [18] for clinical and radiographic evaluations, respectively. Additionally, lesion size was measured using the combined necrotic angle as described by Kerboul et al. [34]. For Stage I hips or patients in whom the lesion was not seen on radiographs, magnetic resonance imaging was used to determine the lesion size. Patients with collapse (Ficat Stage III or greater) were not candidates for this procedure. The radiographic evaluations were conducted by two of the authors (TMS, SDU). We evaluated the overall effectiveness of the small-diameter core decompression technique by combining the results of our study with those of a previously published small-diameter drilling study by Song et al. [73] and compared the proportions of patients who had radiographic failures or underwent additional surgeries to the outcomes of the other modern studies published since 1992.

To address the specific questions asked in this study, we compared the following groups: (1) procedures before 1992; (2) procedures from 1992 forward; (3) reports of nonoperative treatment; and (4) reports using the multiple small-diameter drilling technique. The number and percentage of additional surgeries and radiographic failures were stratified by Ficat stage when possible. For our percutaneous multiple small-diameter drilling cohort we also stratified the results by lesion size. A chi-square analysis was used to compare the differences in outcomes for all the groups that were evaluated. The key variable used for the power analysis was the difference in proportions of patients who underwent additional surgery in the pre-1992 studies compared to the studies from 1992 to 2007. A power analysis was conducted to ensure the comparison of failure rates was sufficiently powered ($p < 0.05$; power: 80%) to reveal the p values necessary to answer the primary research questions in this study. Prior studies that reported on comparisons of core decompression techniques were assessed to determine a clinically justifiable and appropriate effect size [1, 20]. Based on these studies and the success rates of core decompression that we have seen at our institution, we determined that we would need a minimum proportions sample size of 186 hips to identify an improvement from 60 percent to 45 percent of patients undergoing additional surgery. All comparisons were conducted using 95% confidence intervals where a p value of less than 0.05 was considered significant. We used SPSS version 13.0 software (SPSS Inc, Chicago, IL) for all analyses.

Results

Overall, the success rates were higher for the studies that reported core decompressions performed during the last 15 years (Table 2) compared to procedures performed before 1992 (Table 3). From these reports, there were 1337 hips treated before 1992 and 1268 hips since 1992. The proportion of patients surviving without additional surgery increased ($p < 0.001$) from 59% (range, 29%–85%) in the earlier studies to 70% (range, 39%–100%) in the more recent reports. Similarly, the radiographic success also increased ($p = 0.027$) from 56% (range, 0–94%) for the pre-1992 cohort to 63% (range, 22%–90%). Stratification by Ficat stage (Table 4) showed there were fewer ($p < 0.001$) patients who were Ficat Stage III after 1992.

The reports of nonoperative treatment (Table 5) had higher proportions of failures compared to the core decompression studies from 1992 to 2007. There were 791 hips in 18 studies between 1960 and 2007. In the studies that reported relevant data, the proportion of patients who underwent surgery by final followup at a mean of 67%

Table 2. Literature review of core decompression outcomes for 1992 to 2007 patient cohort studies

Author/Year	Number of hips	Months followup (range)	Additional surgery (%)	Radiographic failure (%)
Kane et al./1996 [33]	19	(24–60)	11 (58)	11 (58)
Markel et al./1996 [47]	54	(2–53)	26 (48)	–
Chang et al./1997 [11]	84	57 (24 to 165)	22 (26)	59 (70)
Mazieres et al./1997 [48]	20	24	9 (45)	9 (45)
Powell et al./1997 [64]	34	48	9 (26)	–
Iorio et al./1998 [30]	33	64 (24–120)	11 (33)	18 (55)
Scully et al./1998 [68]	98	(21–50)	52 (53)	–
Chen et al./2000 [12]	27	28 (12–128)	–	10 (37)
Lavernia and Sierra/2000 [41]	67	41	16 (24)	–
Maniwa et al./2000 [46]	26	94 (53–164)	8 (31)	–
Specchiulli et al./2000 [74]	20	67	4 (20)	4 (20)
Piperkovski/2001 [62]	39	48	4 (10)	–
Yoon et al./2001 [97]	39	61 (24–118)	19 (49)	–
Aigner et al./2002 [2]	45	69 (31–120)	7 (16)	12 (27)
Hernigou et al./2003[a] [23]	189	84 (60–132)	34 (18)	39 (21)
Wirtz et al./2003[†] [93]	51	(36–132)	18 (35)	–
Gangji et al./2004[a] [20]	10	24	0 (0)	1 (10)
Gangji et al./2004 [20]	8	24	2 (25)	5 (63)
Lieberman et al./2004[a] [45]	17	53 (26–94)	3 (18)	3 (18)
Bellot et al./2005 [4]	31	(1–176)	19 (61)	19 (61)
Ha et al./2006 [21]	18	(50–96)	–	14 (78)
Neumayr et al./2006 [59]	17	36	3 (18)	–
Veillette et al./2006[c] [89]	58	24 (6–52)	9 (16)	16 (28)
Marker et al./2007[b, ††]	79	24 (20–39)	27 (34)	27 (34)
Shuler et al./2007[c] [69]	22	39 (27–59)	3 (14)	3 (14)
Song et al./2007[b] [73]	163	87 (60–134)	50 (31)	–
Total	1268	63 (1–176)[‡]	366 (30)[‡‡]	250 (37)[¥]

[†] Previous study not listed includes Wirtz et al. [92]; [††] Results of the present study. Previous study not listed includes Mont et al. [56]; [‡] Weighted average follow-up; [‡‡] Data for total of 1223 hips; [¥] Data for total of 680 hips; [a] biologics; [b] multiple small diameter drilling; [c] tantalum; – = Data meeting our definition of additional surgery or radiographic failure was not available.

(range, 14% to 91%) was statistically higher than the modern reports ($p < 0.001$). Similarly, the mean reported radiographic failure rates at 72% (range, 41% to 100%) were considerably higher ($p < 0.001$). Only 164 natural history patients were reported between 1992 and 2007, although the clinical and radiographic failure rates were similar between this group of patients and those evaluated before 1992.

The results using the small-diameter drilling technique at our institution combined with those reported by Song et al. [73] were similar to other studies of the last 15 years (Table 6). At our institution, there were 21 patients (27 hips, 34%) who underwent additional surgery. The distribution of Harris hip scores by number of hips were: 25 (90 points or greater), 24 (80–89 points), seven (70–79 points), and 23 (less than 70 points). Excluding the patients who underwent additional surgery, the mean Harris hip score was 89 points (range, 72–100 points). Two patients (three hips) both had scores of 72 points but did not receive additional treatment. The patient who had bilateral osteonecrosis reported moderate pain in both hips. The other patient progressed from Ficat stage I to Ficat Stage II and his reported pain scores increased from mild (30 points) preoperatively to moderate (20 points) at final followup. There were 27 hips (34%) that showed radiographic progression of the disease to collapse following core decompression.

Patients in our small-diameter drilling cohort with higher Ficat stages and larger lesion sizes had increased failure rates. The proportion of hips ($n = 13$, 59%) with a large lesion (combined necrotic angle $\geq 200°$) that underwent additional surgery was greater ($p = 0.008$) than the proportion of hips ($n = 14$, 25%) that had small lesions (a combined necrotic angle $< 200°$) and underwent additional surgery. Similarly, the rate of additional surgery was higher ($p = 0.044$) for hips that were Ficat Stage II (52%)

Table 3. Literature review of core decompression outcomes for pre-1992 patient cohort studies

Author/Year	Number of hips	Months follow-up (range)	Additional surgery (%)	Radiographic failure (%)
Solomon/1981 [72]	22	24 (6–48)	5 (23)	–
Ficat/1985 [18]	133	114 (60–204)	–	28 (21)
Camp and Colwell/1986 [9]	40	18 (3–40)	6 (15)	8 (20)
Hopson and Siverhus/1988 [28]	20	39 (12–78)	12 (57)	–
Saito et al./1988 [67]	17	48 (24–168)	–	9 (53)
Tooke et al./1988 [86]	45	36 (12–84)	16 (36)	16 (36)
Aaron et al./1989 [1]	50	26	28 (56)	32 (64)
Aaron et al./1989[a] [1]	56	27	18 (32)	22 (39)
Beltran et al./1990 [5]	34	23 (11–47)	–	16 (47)
Trancik et al./1990[a] [87]	11	45 (24–60)	5 (45)	11 (100)
Kristensen et al./1991 [37]	18	39 (12–60)	–	3 (17)
Stulberg et al./1991 [83]	28	27	8 (29)	21 (75)
Robinson and Springer/1993 [66]	19	48	3 (16)	4 (21)
Lafforgue et al./1993 [38]	27	46	–	17 (63)
Leder and Knahr/1993 [43]	47	44 (24–100)	9 (19)	11 (23)
Holman et al./1995 [27]	31	(18–67)	14 (45)	8 (40)*
Koo et al./1995 [36]	18	(minimum 24)	–	14 (78)
Smith et al./1995 [71]	114	40 (24–78)	64 (56)	–
Mont et al./1997[†] [52]	79	144 (48–216)	37 (47)	–
Mont et al./1998 [53]	68	144 (48–216)	48 (71)	48 (71)
Bozic et al./1999 [7]	54	120 (24–196)	28 (52)	34 (62)
Simank et al./1999 [70]	94	72 (18–180)	32 (34)	–
Steinberg et al./2001[††,a] [82]	312	48 (3–155)	113 (36)	–
Total	1337	65 (3–216)[‡]	446 (41)[‡‡]	302 (44)[¥]

* Radiographic outcomes were only provided for 20 hips; [†] Previous studies not listed include Hungerford and Zizic [29] and Fairbank et al. [17]; [††] Other studies not listed include Steinberg et al. [75, 77–80] and Israelite et al. [31]; [‡] Weighted average follow-up; [‡‡] Data for total of 1090 hips; [¥] Data for total of 685 hips; [a] core decompression combined with electrical stimulation; – = Data meeting our definition of additional surgery or radiographic failure was not available.

preoperatively, compared to Ficat Stage I (26%). The best results were seen in patients who had small lesions and Ficat Stage I prior to treatment with 79% of these hips showing no radiographic stage progression.

Discussion

While core decompression is relatively commonly performed for ON of the femoral head, the variations in reported techniques and drilling procedures make it difficult to interpret the efficacy of these procedures. Some recent reports using innovative techniques such as growth and differentiation factors to fill the core decompression tract suggest excellent results, although the literature contains a wide variety of results. Because of the relatively small number of procedures reported for each of these studies reporting on varied techniques, we analyzed recent techniques by comparing studies that reported procedures that were performed before 1992 to reports that had procedures between 1992 and 2007. The primary question of our study was whether the outcomes reported in the recent studies were better than those prior to 1992 in terms of reduced proportions of patients having additional surgeries and/or showing radiographic signs of femoral head collapse. Additionally, using these same measures, we asked whether modern core decompression techniques provided better outcomes than non-operative treatment.

One of the limitations of this study was the small numbers of patients in many of the reports reviewed. Another limitation was that in some cases it was difficult to determine when the core decompressions were performed in order to stratify the study as pre-1992 or 1992 to 2007. However, we believe our approach of using the publication date and the mean followup to estimate when procedures were performed would correctly stratify the majority of the studies that were close to our 1992 cutoff. In addition, there were only midterm mean followups (range, 18 months to 144 months) for many studies, and the long-term outcome of core decompression is unclear. Another limitation was

Table 4. Comparison of historical and modern core decompression studies

Data*	Studies prior to 1992	Studies from 1992 to 2007	p-Value
Demographic variables			
Mean age (range)	39 (15–83) years	39 (13–72) years	–
Mean followup (range)	65 (3–216) months	63 (1–176) months	–
Preoperative ficat stage			
Ficat Stage I	32%	29%	0.302
Ficat Stage II	42%	52%	< 0.001†
Ficat Stage III	27%	19%	< 0.001†
Outcomes			
Additional surgery			
Overall	41%	30%	< 0.001†
Ficat Stage I	15%	20%	0.413
Ficat Stage II	44%	35%	0.056
Ficat Stage III	67%	66%	0.939
Radiographic failure			
Overall	44%	37%	< 0.001†
Ficat Stage I	22%	21%	0.919
Ficat Stage II	47%	48%	0.887
Ficat Stage III	66%	50%	0.708

* Some studies did not stratify by Ficat stage and/or report both outcome measures.

† Values were statistically significant.

the level of evidence for the scientific literature reviewed. As previously noted, most of the studies were Level IV and there were few Level I studies. There is a need for more prospective randomized multicenter studies that further analyze some of these newer techniques which will need longer followup and larger patient numbers in the future. Additionally, if standardized clinical and radiographic evaluation criteria were adopted, future meta-analyses could provide more valid comparisons across studies. The limitations of our assessment of the percutaneous multiple small-diameter drilling technique were similar to those of other studies: a limited number of patients from a single center, no long-term followup, and lack of a randomized control group. Nevertheless, we do not believe these limitations detract from the overall results of the present study, as in general, the results of all of the different techniques were somewhat comparable and appear better than the natural history.

The meta-analysis and our cohort of multiple small-diameter drilling patients suggest that core decompression provides fewer treatment failures than nonoperative treatment. Although there are improvements in overall success rates for the procedures performed from 1992 to present, the stratification of the meta-analysis data by Ficat stage suggests that patient selection may have been the primary reason for this gain as there were fewer Ficat Stage III patients in the later studies. However, based on the improvements in clinical outcomes for Ficat Stage II hips, it appears that modern core decompression techniques did provide improved outcomes for some subsets of patients.

The literature review (Table 2) suggests patients who have hips with Ficat Stage III disease are more likely to have radiographic progression, clinical failure, and have additional surgeries, suggesting these patients may not be appropriate candidates for this procedure. Although there appears to have been increased patient selectivity in the past 15 years in terms of fewer Ficat Stage III hips being treated with core decompressions, a number of surgeons continue to use this procedure. Based on the literature review, there were 132 patients (18% of all patients in studies after 1992 that stratified hips by Ficat stage) who were Stage III and treated using core decompression. These patients were included in 9 of the 35 studies (26%) after 1992. A recent study by Tingart et al. [85] reported similar results. They reported 11% of surgeons they surveyed used core decompression for patients who were Ficat Stage III or IV. While some surgeons may be using core decompression only as a pain-relieving procedure or assessing the potential efficacy of modern techniques in Stage III hips, we continue to recommend that other treatment options such as total hip arthroplasty or resurfacing be used for these difficult to treat patients.

Our own data from patients in whom we used small-diameter multiple drilling also confirms that the prognosis is influenced by the extent of the lesion size (Table 3). These results are similar to a prospective study of 73 hips by Steinberg et al. [76] which evaluated the effect of lesion size on the outcome of core decompression. They defined three groups based on lesion size: small, less than 15% of femoral head involvement; medium, 15% to 30%; and large, greater than 30%. The difference between the percentage of patients who had small lesions and later underwent total hip arthroplasty (7%) was lower than patients with large lesions (33%) who received a total hip arthroplasty.

The overall success rate of our cohort of small-diameter multiple drilling patients was similar to two other recent studies that used a similar technique. In one of these studies, Yan et al. [95] reported an improvement in Harris hip score from a mean of 58 points (range, 46–89 points) preoperatively to a mean of 86 points (range, 70–94 points) at a minimum 2-year followup. In the other study by Song et al. [73], 79% of patients who had Ficat Stage I disease had no additional surgery at a minimum 5-year followup. The rationale and advantages for the small-diameter drilling presented in these prior studies were that: (1) the small diameter drill can more easily reach the anterior portion of

Table 5. Literature review of nonoperative treatment outcomes

Author/Year	Number of hips	Months followup (range)	Additional surgery (%)	Radiographic failure (%)
Coste et al./1965 [16]	100	24	–	73 (73)
Merle d'Aubigne et al./1965 [49]	90	36 (12–48)	–	61 (68)
Boettcher et al./1970 [6]	5	(minimum 24)	–	4 (80)
Zizic and Hungerford/1985 [98]	15	44	–	13 (87)
Musso et al./1986† [58]	50	30	34 (68)	41 (82)
Steinberg et al./1989 [79]	55	21 (6–120)	46 (84)	–
Churchill and Spencer/1991 [13]	18	60	9 (50)	8 (44)
Ohzono et al./1991 [61]	115	63	–	78 (68)
Stulberg et al./1991 [83]	22	27	20 (91)	11 (50)
Robinson and Springer/1993 [66]	16	39 (24–61)	7 (44)	9 (56)
Bradway and Morrey/1993 [8]	15	23 (3–66)	13 (87)	15 (100)
Koo et al./1995 [36]	19	(minimum 24)	–	15 (79)
Jergesen et al./1997 [32]	19	111 (51–81)	11 (58)	7 (41)*
Lai et al./2005 [39]	25	24	17 (68)	19 (76)
Ha et al./2006 [21]	19	(50–96)	–	15 (79)
Hernigou et al./2006†† [26]	121	168 (120–240)	91 (75)	93 (77)
Neumayr et al./2006 [59]	21	36	3 (14)	–
Morse et al./2007 [57]	67	23 (17–31)	20 (30)	–
Total	792	53 (3–240)‡	271 (63)‡‡	455 (72)¥

* Radiographs were only available for 17 patients; † Previous study not listed includes Bassett et al. [3]; †† Previous studies not listed include Hernigou et al. [23, 25]; ‡ Weighted average follow-up; ‡‡ Data for total of 429 hips; ¥ Data for total of 630 hips; – = Data meeting our definition of additional surgery or radiographic failure was not available.

Table 6. Multiple small-diameter drilling compared to other modern studies

Data	Small-diameter technique	Other 1992–2007 studies	p Value
Demographics			
Number of hips	242	1026	–
Mean age (range)	39 (18–72)	39 (12–71)	–
Mean followup (range)	80 (36–134)	58 (1–176)	–
Outcomes			
Additional surgery	32%	29%	0.520
Radiographic failure	34%	37%	0.437

the femoral head, an area frequently involved in osteonecrosis; (2) there is minimal morbidity; (3) the risk of weakening or penetrating the femoral head and injuring the articular cartilage when using a large-diameter trephine for multiple drillings is potentially reduced; and (4) the risk of stress risers that can lead to a subtrochanteric fracture is also reduced.

The literature review and our data suggest recent techniques provide better clinical scores or radiographic outcomes than pre-1992 studies of core decompression. However, it is unclear whether this improvement is due to improved patient selection or surgical technique. At a minimum, the additional accumulation of successful reports in the last decade confirms that core decompression is a safe and effective procedure for the treatment of early stages of osteonecrosis of the femoral head. Based on the results of our experience as well as other studies, we will use core decompression to treat patients who have early small- and medium-sized lesions and are Ficat Stage I or II. Additionally, the midterm followup of the multiple small-diameter core decompression patients at our institution was longer than most studies, and had a success rate similar to or higher than other reports, which makes this technique the authors' preferred modality. However, prospective, randomized studies are recommended to verify these observations before this technique can be recommended as a standard for practicing surgeons.

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