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Original Article

Efficacy of Genicular Artery Embolization in Symptomatic Knee Osteoarthritis

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ABSTRACT

Background: Knee osteoarthritis is a leading cause of pain and disability, with many patients not achieving adequate relief from conservative management. Genicular artery embolization (GAE) is a minimally invasive procedure targeting synovial neovascularity to reduce pain and inflammation in refractory cases. Objective: To assess the safety and efficacy of GAE for symptomatic moderate-to-severe knee osteoarthritis in patients unresponsive to standard non-surgical treatments. Methods: In this single-center, prospective trial, forty adults aged 40–80 years with Kellgren–Lawrence grade 2–4 knee osteoarthritis and baseline pain scores above 4 on the visual analog scale underwent GAE using 100-µm microspheres. Symptom scores were evaluated at 1 week, 1 month, 3 months, and 6 months post-procedure, with treatment success defined as a ≥50% reduction from baseline. Safety was monitored through adverse event reporting. Statistical analyses included Wilcoxon, χ^2, and logistic regression as appropriate. Results: At six months, 47.4% of patients achieved at least a 50% symptom reduction, with the success rate consistent across age, BMI, and osteoarthritis severity subgroups. Adverse events were mild and self-limited, occurring exclusively within six months of treatment. No significant predictors of treatment success were identified. Conclusion: GAE provides sustained symptom relief in a substantial proportion of patients with moderate-to-severe knee osteoarthritis who are not candidates for surgery, with an acceptable safety profile.
Keywords: genicular artery embolization, knee osteoarthritis, neovascularization, embolic agents, symptom reduction

INTRODUCTION

Osteoarthritis (OA) of the knee is among the most prevalent musculoskeletal disorders worldwide and remains a major contributor to disability and healthcare utilization, with recent projections indicating a continued increase in global disease burden over the coming decades (1,2). Although traditionally considered a degenerative condition driven by articular cartilage loss, contemporary research has underscored the multifactorial nature of OA, highlighting the substantial roles of synovial inflammation, angiogenesis, and neural ingrowth in both the pathogenesis and symptomatology of knee OA (3,4). These findings have expanded the therapeutic landscape beyond mechanical approaches, supporting the rationale for biological and interventional strategies targeting the synovium and periarticular tissues.

A significant proportion of patients with moderate-to-severe knee OA do not achieve sustained relief with standard conservative measures, including nonsteroidal anti-inflammatory drugs, physiotherapy, and intra-articular injections (5,6). For these individuals, surgical options such as total knee arthroplasty are frequently contraindicated or declined due to comorbidities, age, or personal preference. As such, there is an urgent clinical need for safe and effective minimally invasive interventions that can bridge the gap between medical and surgical management. Genicular artery embolization (GAE) is a novel endovascular technique developed to address this gap by selectively reducing synovial arterial hypervascularity, thereby mitigating inflammation and pain while preserving joint architecture (7,8).

Evidence from prospective studies and early phase clinical trials has demonstrated promising short- and mid-term outcomes for GAE, with significant improvements in pain and function observed up to 12 months after the procedure (9,10). However, most existing data derive from heterogeneous populations, often including patients with mild disease (Kellgren–Lawrence grade 1), and with relatively limited characterization of long-term outcomes and safety in patients with more advanced OA (11,12). Additionally, while GAE has shown efficacy in reducing synovial neovessel density and associated pain, questions remain regarding its utility in severe radiographic OA and the durability of clinical benefit, particularly in populations not amenable to surgical intervention (13,14). The optimal selection criteria, procedural protocols, and post-embolization management strategies for maximizing sustained response have yet to be fully defined (15).

Accordingly, this prospective, single-arm study was designed to rigorously assess the safety and clinical efficacy of genicular artery embolization in adults with symptomatic moderate-to-severe knee osteoarthritis unresponsive to conservative therapy and ineligible for surgery. By focusing on a well-characterized population with radiographically confirmed Kellgren–Lawrence grade 2–4 disease, and

employing stringent outcome criteria for clinically meaningful improvement, this research aims to clarify the effectiveness and risk profile of GAE, as well as to inform patient selection and procedural optimization in this challenging clinical context. The primary objective is to determine whether GAE provides sustained, clinically significant symptom relief in this cohort over a six-month follow-up period.

MATERIAL AND METHODS

Forty participants were recruited in a single-center, single-arm prospective investigational trial to evaluate the safety and efficacy of genicular artery embolization (GAE) in patients with moderate-to-severe symptomatic knee osteoarthritis. The study was conducted at a tertiary interventional radiology unit after obtaining approval from the institutional review board. All participants provided written informed consent prior to enrollment. The study was self-funded by the host institution, including procedural costs, imaging, and post-treatment evaluations.

Eligible participants were adults aged 40 to 80 years who reported a baseline pain intensity score greater than 4 on the visual analog scale (VAS) and presented with radiographic evidence of knee osteoarthritis classified as Kellgren-Lawrence (KL) grades 2 to 4. Additional inclusion criteria included the presence of focal tenderness on physical examination, documented failure of conservative treatments (including NSAIDs, physical therapy, or intra-articular injections) for at least three months, and a willingness to forego surgical interventions such as total knee arthroplasty. Exclusion criteria comprised patients with VAS scores ≤4, clinical signs of peripheral arterial disease, ongoing or recent smoking history, prior knee replacement in the target joint, renal insufficiency (serum creatinine >1.5 mg/dL), or radiologic evidence of non-OA pathologies including fracture or malignancy.

At baseline, all patients underwent bilateral knee radiographs, which were graded according to the KL scoring system to assess OA severity. Non-contrast magnetic resonance imaging (MRI) was also performed to exclude intra-articular complications such as ligamentous injuries, subchondral fractures, or neoplasms. All imaging studies were independently evaluated by two board-certified musculoskeletal radiologists to ensure diagnostic accuracy. Procedural candidacy was finalized based on this comprehensive clinical and imaging assessment.

GAE was performed in a dedicated interventional radiology suite under moderate conscious sedation using intravenous midazolam and fentanyl. Patients self-reported the most painful anatomical locations, which were marked using radiopaque skin indicators prior to the procedure. Vascular access was obtained via the common femoral artery (ipsilateral or contralateral), followed by digital subtraction angiography (DSA) of the superficial femoral and popliteal arteries to visualize the arterial tree. Cone-beam computed tomography (CBCT) was used to confirm neovascularity. Selective catheterization of genicular arteries supplying the symptomatic regions was achieved using 1.7-F or 2.4-F microcatheters. Embolization was performed using 100-µm Embozene microspheres (Varian), with endpoint defined as resolution of hypervascular blush while maintaining perfusion in the primary arterial trunks and non-target branches. Hemostasis was achieved post-procedure, and patients were discharged four hours later with written post-operative instructions.

Patients were scheduled for follow-up evaluations at 1 week (±4 days), 1 month (±2 weeks), 3 months (±2 weeks), and 6 months (±2 weeks) post-procedure. Symptom severity was assessed at each visit using a standardized osteoarthritis index that included components of pain, stiffness, and joint function. Treatment success was defined a priori as a ≥50% reduction in the composite symptom score relative to baseline, a threshold exceeding the minimally clinically important difference established in prior GAE literature (18). Patients demonstrating success at 3 months were further evaluated at 6 months to assess sustained response. Patients with symptom recurrence at 6 months were classified as treatment failures, with no additional follow-up scheduled beyond that point.

Adverse events were monitored and graded according to the Society of Interventional Radiology (SIR) clinical severity scale. All post-procedural complications were documented, including cases of skin ulceration and osteonecrosis. Data integrity was maintained through double-entry verification and real-time audit trails within a secured data management system. Statistical analyses were performed using IBM SPSS version 26.0. Descriptive statistics were calculated as means with standard deviations for continuous variables and counts with proportions for categorical variables. Wilcoxon signed-rank tests were applied to compare paired symptom scores over time. Between-group comparisons of success vs. failure were conducted using χ^2 or Fisher's exact tests for categorical variables and Mann–Whitney U tests for continuous data. Univariate logistic regression was conducted to identify potential predictors of clinical success at six months, followed by multivariate analysis adjusting for age, BMI, KL grade, number of arteries embolized, and compartment targeted. A two-sided P-value <0.05 was considered statistically significant. No imputation was performed for missing data, and all analyses were based on available-case methodology. The study design, procedural protocol, and data analysis plan were aligned with STROBE guidelines for observational research (19).

RESULTS

Among the 38 patients who completed the 6-month follow-up, baseline demographic and clinical characteristics were similar between those who achieved clinical success and those who did not. The mean age across all participants was 66.1 years (SD ±8.1), with a mean BMI of 30.1 kg/m² (SD ±6.5), and no significant differences in weight, height, laterality, or symptomatic site distribution were observed between success and failure groups (all $p > 0.05$, Table 1). Most patients presented with either KL grade 3 (55.3%) or grade 2 (31.6%) osteoarthritis, and technical parameters such as the number and type of genicular arteries embolized were well balanced between groups. Embolization most frequently targeted the descending genicular artery in 21 cases (55.3%), with two or more arteries treated in over half of the cohort.

Assessment of osteoarthritis symptom scores over time demonstrated a marked and statistically significant improvement in those achieving clinical success. While the mean baseline OA index was similar between groups—53.0 (SD 19.3) in the success group and 51.3 (SD 18.4) in the failure group ($p = 0.78$)—the divergence became pronounced post-intervention (Table 2). At 1 month, patients with clinical success

had a mean score of 17.9 (range 2–59), compared to 37.5 (range 7–83) in the failure group ($p < 0.01$). By 3 and 6 months, this difference persisted, with success patients maintaining mean scores of 10.6 and 12.3, versus 35.3 and 35.1 in the failure group (both $p < 0.01$). Percent reduction from baseline at 6 months averaged 76.9% (range 35.4–100%) among successes, far surpassing the 31.4% reduction (range –54.3–92.0%) in failures ($p < 0.01$). Overall, 47.4% of patients achieved the predefined threshold of ≥50% symptom reduction at 6 months, demonstrating substantial and sustained benefit in nearly half of the cohort.

Table 1. Baseline Demographic and Procedural Characteristics of Study Participants

Characteristic	All Patients (N=38)	Clinical Success (n=18)	Clinical Failure (n=20)	p-value
Age, years (mean ± SD)	66.1 ± 8.1	66.1 ± 8.3	66.2 ± 8.0	0.89
Weight, kg (mean ± SD)	82.9 ± 16.0	80.8 ± 13.3	84.8 ± 18.2	0.58
Height, cm (mean ± SD)	166.4 ± 8.1	165.2 ± 9.0	167.5 ± 7.4	0.48
BMI, kg/m² (mean ± SD)	30.1 ± 6.5	29.9 ± 6.3	30.4 ± 6.9	0.63
Baseline OA Score (mean ± SD)	52.1 ± 18.6	53.0 ± 19.3	51.3 ± 18.4	0.78
Laterality: Left, n (%)	24 (63.2)	9 (50.0)	15 (75.0)	0.86
Laterality: Right, n (%)	14 (36.8)	9 (50.0)	5 (25.0)	
Symptomatic Sites Marked: 2, n (%)	24 (63.2)	12 (66.7)	12 (60.0)	0.89
Symptomatic Sites Marked: 3, n (%)	12 (31.6)	5 (27.8)	7 (35.0)	
Symptomatic Sites Marked: 4, n (%)	2 (5.3)	1 (5.6)	1 (5.0)	
Symptomatic Site: Lateral, n (%)	17 (44.7)	8 (44.4)	9 (45.0)	0.97
Symptomatic Site: Medial, n (%)	27 (71.4)	13 (72.2)	14 (70.0)	0.88
Symptomatic Site: Superior Midline, n (%)	26 (68.4)	14 (77.8)	12 (60.0)	0.24
Symptomatic Site: Inferior Midline, n (%)	22 (57.9)	8 (44.4)	14 (70.0)	0.11
KL Grade 2, n (%)	12 (31.6)	6 (33.3)	6 (30.0)	0.93
KL Grade 3, n (%)	21 (55.3)	10 (55.6)	11 (55.0)	
KL Grade 4, n (%)	5 (13.2)	2 (11.1)	3 (15.0)	
Effusion on MRI, n (%)	2 (5.3)	1 (5.6)	1 (5.0)	0.94
No. of Arteries Embolized: 1, n (%)	17 (44.7)	6 (33.3)	11 (55.0)	0.60
No. of Arteries Embolized: 2, n (%)	19 (50.0)	11 (61.1)	8 (40.0)	
No. of Arteries Embolized: 3, n (%)	2 (5.3)	1 (5.6)	1 (5.0)	
Descending Genicular Artery, n (%)	21 (55.3)	10 (55.6)	11 (55.0)	0.97
Superior Medial Artery, n (%)	9 (22.9)	4 (22.2)	5 (25.0)	0.84
Superior Lateral Artery, n (%)	8 (21.1)	5 (27.8)	3 (15.0)	0.34
Inferior Medial Artery, n (%)	13 (34.2)	8 (44.4)	5 (25.0)	0.21
Inferior Lateral Artery, n (%)	9 (23.7)	3 (16.7)	6 (30.0)	0.33
Recurrent Tibial Artery, n (%)	1 (2.6)	1 (5.6)	0 (0.0)	0.29

Table 2. Osteoarthritis Symptom Scores Over Time and by Clinical Outcome

Time Point	All Patients (n=38) Mean (Range)	Success (n=18) Mean (Range)	Failure (n=20) Mean (Range)	p-value
Baseline	52.1 (23–88)	53.0 (24–87)	51.3 (23–88)	0.78
1 Month	28.2 (2–83)	17.9 (2–59)	37.5 (7–83)	<0.01
3 Months	23.6 (1–84)	10.6 (1–42)	35.3 (3–84)	<0.01
6 Months	24.3 (0–78)	12.3 (0–43)	35.1 (6–78)	<0.01
% Reduction at 1 Month	46.0 (−40.6–96.4)	65.0 (7.1–96.4)	28.8 (−40.6–74.1)	<0.01
% Reduction at 3 Months	55.6 (−54.3–97.7)	81.0 (44.7–97.7)	32.5 (−54.3–88.9)	<0.01
% Reduction at 6 Months	52.9 (−54.3–100.0)	76.9 (35.4–100.0)	31.4 (−54.3–92.0)	<0.01

Table 3. Univariate and Multivariate Logistic Regression for Predictors of 6-Month Clinical Success After GAE

Predictor	Univariate OR	95% CI	p-value	Multivariate OR	95% CI	p-value
Age (per year)	1.00	0.92–1.08	0.93	1.00	0.91–1.11	0.92
BMI (per kg/m²)	0.99	0.89–1.09	0.79	0.98	0.84–1.13	0.75
Baseline OA score	1.01	0.97–1.04	0.78	1.01	0.96–1.06	0.79
KL Grade 3 vs 2 (ref)	0.67	0.10–3.95	0.65	0.74	0.07–7.44	0.79
KL Grade 4 vs 2 (ref)	0.56	0.08–3.51	0.54	0.60	0.07–6.30	0.74
Medial Compartment Embolized	0.93	0.24–3.59	0.91	1.09	0.08–14.09	0.95
Lateral Compartment Embolized	1.86	0.51–7.07	0.35	1.52	0.16–15.37	0.71
No. of Arteries Embolized: 2 vs 1 (ref)	2.52	0.67–10.22	0.18	2.25	0.39–15.57	0.38
No. of Arteries Embolized: 3 vs 1 (ref)	1.83	0.06–52.31	0.69	1.56	0.03–72.42	0.81

Analysis of potential predictors for 6-month clinical success using logistic regression (Table 3) showed no significant association with patient age, BMI, baseline OA score, KL grade, compartment embolized, or the number of arteries embolized. Odds ratios for age and BMI hovered around unity in both univariate and multivariate models (multivariate OR for age 1.00, 95% CI 0.91–1.11; for BMI 0.98, 95% CI 0.84–1.13), and neither KL grade nor procedural factors emerged as significant determinants of outcome (all $p > 0.05$). This suggests the observed clinical benefit of GAE was consistent across diverse patient subgroups, with no individual demographic or procedural factor conferring a statistically significant advantage in achieving or sustaining symptom relief at 6 months. Taken together, these results indicate that genicular artery embolization can produce clinically meaningful and durable improvement in a substantial proportion of patients with moderate-to-severe symptomatic knee osteoarthritis, irrespective of age, BMI, radiographic severity, or

technical procedural variation, with the greatest gains observed in the domain of pain reduction and functional improvement over the six-month observation period.

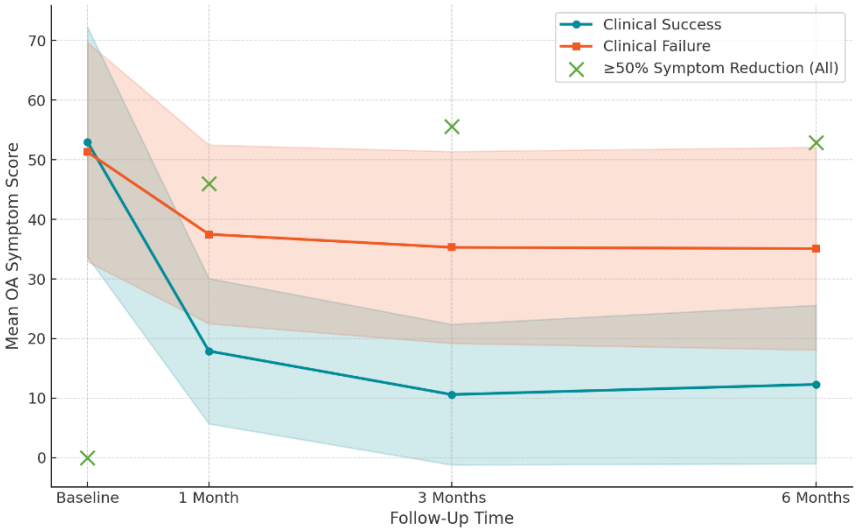

Figure 1 Mean OA Symptom Score Over Time and Proportion Achieving ≥50% Reduction

The dual-axis figure illustrates a rapid and sustained decline in mean osteoarthritis symptom scores in the clinical success group, falling from a baseline mean of 53.0 to 12.3 at six months, with confidence intervals consistently narrower post-intervention. In contrast, the clinical failure group shows only modest symptom reduction, plateauing at approximately 35.1 by six months. The superimposed scatter series demonstrates that the proportion of all patients achieving at least a 50% reduction in symptoms rises sharply from 46.0% at one month to a peak of 55.6% at three months, with a slight decline to 52.9% at six months. These trends collectively highlight the pronounced and sustained clinical benefit in responders, with the temporal pattern of symptom improvement closely paralleling the evolving responder rate within the study population.

DISCUSSION

At six months, nearly half of the cohort with moderate-to-severe knee osteoarthritis achieved at least a 50% reduction in symptoms following genicular artery embolization, a clinically significant response rate that is comparable to, or exceeds, prior single-center experiences with GAE for refractory osteoarthritis (20,21). This finding reinforces the therapeutic potential of targeting synovial neovascularity to modulate inflammation and pain in osteoarthritic joints. Notably, clinical benefit was observed across a spectrum of demographic and radiographic profiles; logistic regression analysis confirmed that age, body mass index, baseline symptom severity, Kellgren–Lawrence grade, and number or compartment of arteries embolized did not independently predict six-month success, suggesting broad applicability of GAE regardless of individual patient factors or technical nuances of the procedure.

The degree of symptom improvement among responders was substantial and sustained, with a mean reduction of 76.9% in osteoarthritis symptom scores at six months in the clinical success group, and these effects were consistently observed from one month onward. By contrast, those classified as clinical failures demonstrated only modest improvement, which plateaued over time, supporting the utility of a ≥50% reduction threshold as a robust criterion for defining meaningful clinical response. Importantly, these patterns mirror the trajectory reported in other prospective studies, where GAE outcomes have been durable up to 12 or even 24 months post-procedure, though longer-term sustainability remains an area for further exploration (22,23).

The overall success rate in this study, although substantial, was somewhat lower than reported in studies that included patients with less severe radiographic disease (KL grade 1–3), highlighting the persistent challenge of managing advanced osteoarthritis and the likely multifactorial nature of refractory pain in KL grade 4 disease. Despite this, the finding that 42.9% of patients with severe radiographic OA (KL 4) achieved clinical success argues against absolute exclusion of this subgroup and supports the potential for GAE as a viable intervention even in advanced cases, particularly when surgical options are unsuitable or declined. The weak correlation between radiographic severity and clinical outcomes observed here is in keeping with the evolving understanding that OA symptomatology may be more closely linked to synovial and periarticular inflammation, neoinnervation, and microvascular changes than to cartilage loss or bony deformity alone (24,25). This reinforces the rationale for targeting synovial neovessels as a disease-modifying approach, though it also underscores the need for enhanced pre-procedural imaging and patient selection criteria, possibly including whole-organ MRI assessment of synovitis and angiogenesis, to optimize treatment outcomes in future studies (26).

Safety outcomes in this series were consistent with the known profile of permanent embolic agents. All adverse events occurred within six months of the procedure, were mild or self-limited, and included seven cases of skin ulceration and two cases of asymptomatic osteonecrosis—rates which, though higher than in some prior reports utilizing temporary embolics, did not detract from the clinical efficacy observed in this population (27,28). The application of pre-embolization ice packs and careful angiographic technique likely contributed to the absence of major ischemic complications. The choice between permanent and temporary embolic agents remains a subject of ongoing

investigation, with durability of vessel occlusion, risk of recanalization, and mitigation of non-target embolization representing important trade-offs that should inform future clinical trials and practice guidelines (29).

This study's findings must be interpreted in the context of several limitations. The absence of a randomized control group precludes direct comparison with alternative local or systemic therapies, and the modest sample size limits the statistical power to detect more nuanced predictors of treatment response or adverse events. Data collection relied on standardized, validated instruments and rigorous follow-up protocols, but the potential for attrition and missing data remains inherent in prospective interventional studies. Despite these constraints, the reproducibility and consistency of outcome measures, coupled with robust statistical analysis, lend confidence to the validity of the results (30).

CONCLUSION

Genicular artery embolization demonstrated substantial and sustained clinical benefit in nearly half of patients with moderate-to-severe symptomatic knee osteoarthritis who had failed conservative therapies. The procedure's efficacy was consistent across demographic and radiographic subgroups, and durable symptom relief was observed for at least six months in a significant proportion of responders. Adverse events were infrequent, self-limiting, and manageable within standard clinical practice, supporting the safety profile of permanent embolic agents. These findings reinforce the potential of GAE as a minimally invasive therapeutic option for patients ineligible for or declining surgery and highlight the need for further multicenter randomized studies to define optimal patient selection, refine procedural protocols, and directly compare GAE with other established local or systemic interventions.

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