Diagn Interv Radiol 2026; DOI: 10.4274/dir.2026.264171

INTERVENTIONAL RADIOLOGY

ORIGINAL ARTICLE

Genicular artery embolization in primary and secondary knee osteoarthritis: clinical success, patient-perceived satisfaction, and recurrence

Ferdi Çay[1]
Gonca Eldem[1]
Narmin Shirinli[1]
Abdullah Serin[2]
Ömür Çağlar[2]
Bülent Atilla[2]
Buğu Bulat[3]
Umut Kalyoncu[3]
Feza Korkusuz[4]
Bora Peynircioğlu[1]

[1]Hacettepe University Faculty of Medicine, Department of Radiology, Ankara, Türkiye

[2]Hacettepe University Faculty of Medicine, Department of Orthopedics and Traumatology, Ankara, Türkiye

[3]Hacettepe University Faculty of Medicine, Department of Internal Medicine, Ankara, Türkiye

[4]Hacettepe University Faculty of Medicine, Department of Sports Medicine, Ankara, Türkiye

PURPOSE

This study aimed to assess the safety, efficacy, and patient-perceived satisfaction of genicular artery embolization (GAE) for knee osteoarthritis (OA), including secondary OA, and to evaluate predictors of symptom recurrence.

METHODS

Patients treated with GAE for OA-related knee pain at a single center (January 2024–February 2026) were included. Secondary OA was diagnosed when a known underlying cause existed. Outcomes were assessed using a numeric rating scale (NRS) and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire. Clinical success was defined as an NRS improvement ≥ 2 points and a WOMAC reduction ≥ 12 points (the minimally important difference). Recurrence was defined as pain returning to baseline after initial improvement. Periarticular vascular blush was graded (1–3) relative to background soft-tissue stain. All cases used 0.5 g imipenem–cilastatin (IPM/CS) suspended in 10 mL iodinated contrast.

RESULTS

Twenty-four patients (16 women) with 26 treated knees (mean age: 63.2 ± 10.3 years) were analyzed; mean follow-up was 11 ± 5.5 months, and mean decreases in NRS and WOMAC were 4.1 ± 2.8 and 21.3 ± 16.9, respectively. Clinical success was 85% in primary OA and 33.3% in secondary OA; satisfaction was 65.4% (17/26). No severe or permanent complications were observed. Recurrence occurred in 30.8% at a mean of 6.9 ± 5.8 months and was associated with lower total embolic volume (2.0 ± 1.1 mL vs. 4.0 ± 2.8 mL; $P = 0.02$). A periarticular vascular grading system was introduced.

CONCLUSION

GAE appeared to be safe and effective with acceptable satisfaction, although outcomes were less favorable in secondary OA. Higher IPM/CS volume was associated with a lower observed recurrence rate, without an apparent increase in clinical complications. However, given the limited overall sample size and small number of recurrence events, this association should be interpreted as hypothesis-generating rather than as evidence of an independent predictor of recurrence.

CLINICAL SIGNIFICANCE

This study demonstrated the feasibility of GAE in patients with secondary OA. The volume of embolic agent used during GAE may influence post-treatment clinical outcomes in GAE treatment. In this study, a higher IPM/CS volume was associated with a lower observed recurrence, potentially reflecting continued embolization beyond initial angiographic pruning and more complete devascularization.

KEYWORDS

Embolic volume, embolization, knee, periarticular vascularity, recurrence, secondary osteoarthritis

Handling editor: Barbaros Çil

Corresponding author: Ferdi Çay

E-mail: drferdicay@gmail.com

Received 02 June 2026; revision requested 22 June 2026; accepted 17 August 2026.

Epub: 14.09.2026

DOI: 10.4274/dir.2026.264171

You may cite this article as: Çay F, Eldem G, Shirinli N, et al. Genicular artery embolization in primary and secondary knee osteoarthritis: clinical success, patient-perceived satisfaction, and recurrence. *Diagn Interv Radiol*. 14 September 2026 DOI: 10.4274/dir.2026.264171 [Epub Ahead of Print].

One of the most common reasons for knee pain in patients aged > 45 years is osteoarthritis (OA).[1] OA is associated with increased morbidity, particularly due to pain and functional impairment. With increasing life expectancy and the rising prevalence of obesity—two major risk factors for OA—the burden of OA on healthcare systems and public health continues to grow, highlighting the need for more effective treatment options.[2] As OA is no longer considered a simple wear-and-tear disease and local inflammation is now viewed as one of the key factors in its pathogenesis, alleviating that inflammation has become a major goal of OA treatment. This inflammation can stimulate neural growth and thereby increase pain sensitivity.[3]

Genicular artery embolization (GAE) has emerged as a promising procedure that may reduce inflammation in OA by embolizing OA-related neoangiogenic vessels. Embolization of these neoangiogenic vessels, which appear as a hypervascular blush on digital subtraction angiography (DSA), is thought to interrupt the vicious cycle between synovial inflammation and neoangiogenesis in OA.[4,5] However, the exact criteria for defining periarticular hypervascular blush on DSA, which constitutes the target for GAE, remain unclear in the literature, particularly on images obtained from the femoral artery rather than through superselective catheterization of the genicular arteries. On superselective genicular angiograms, normal staining can easily be misinterpreted as hypervascular blush because there is no staining in adjacent areas for comparison. Therefore, a clear definition of the presence and grading of periarticular hypervascular blush on DSA is still lacking.

Main points

- The safety and effectiveness of genicular artery embolization (GAE) in specific subgroups—particularly patients with secondary osteoarthritis (OA)—remain insufficiently studied.
- The concept of hypervascularity in musculoskeletal embolization is heterogeneous rather than uniform.
- GAE with imipenem–cilastatin was associated with less favorable outcomes in patients with secondary OA; however, treatment in this subgroup was not associated with an apparent increase in clinical complications.
- A periarticular vascular blush grading system was introduced based on intensity to better characterize vascularity patterns during GAE.

Short- and long-term safety and efficacy of GAE have been demonstrated in multiple studies.[6-9] However, there are no clearly defined patient selection criteria for GAE, and its efficacy in certain types of OA, such as secondary OA, remains insufficiently studied. Another topic that requires further evaluation is symptom recurrence or the need for repeat intervention after GAE.[10] Cusumano et al.[7] reported a 28% recurrence rate between 12–24 months. Okuno et al.[11] reported a recurrence rate of 10.5% when early and late recurrence rates were combined. In the literature, repeat intervention has generally been performed in patients with insufficient treatment response and/or symptom recurrence; in a meta-analysis published by Taslakian et al.,[9] the repeat intervention rate was 8.3% over 2 years, and Lander et al.[12] reported a 60% repeat intervention rate after 12 months in a small cohort (10 patients). Overall, the recurrence rate after GAE and its potential predictors have not been thoroughly evaluated in the literature.

This study aims to grade periarticular hypervascular blush on DSA, assess the safety and efficacy of GAE in the treatment of OA, including in specific subgroups such as patients with secondary OA, and evaluate potential predictors of symptom recurrence and patient-perceived satisfaction following treatment.

Methods

Ethical approval was obtained from the Research Ethics Committee of Hacettepe University (approval number: 2025/14-46; date of approval: July 8, 2025). Due to the extension of the duration of the study, a second ethics committee approval was obtained (approval number: 2026/15-36, date of approval: July 28, 2026). Patients with OA-related knee pain refractory to conservative treatment, including medical therapy, physical therapy, and/or intra-articular injections, who underwent GAE at Hacettepe University between January 2024 and February 2026 were retrospectively reviewed. The Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines for observational studies were followed in the study.

Diagnoses of OA were made based on radiological and clinical findings by rheumatology, sports medicine, or orthopedics and traumatology. GAE procedures were performed by three experienced interventional radiologists, each with ≥ 7 years of embolization experience. Secondary OA was diagnosed when there was a known underlying cause—such as trauma or inflammatory arthritis—for degenerative changes in the treated knee. In cases of secondary OA related to inflammatory arthritis, the underlying disease was largely under control with systemic medical treatment, except for residual symptoms in the treated knee. Patients treated with GAE for indications other than OA-related pain were excluded from the study. Reasons for exclusion were as follows: seven knees treated for post-total knee arthroplasty (TKA) pain, three treated for control of hemarthrosis, one patient lost to follow-up, and one patient who died of an unrelated cause (Figure 1).

Before each procedure, patients were asked to rate their pain and fill out the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire.[13] Pre- and post-procedure knee pain were assessed with a numeric rating scale (NRS) from 0–10, with 10 indicating the worst pain.

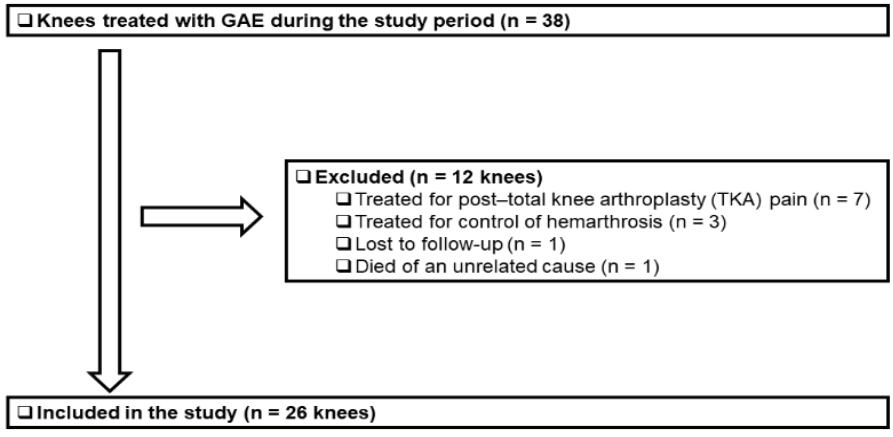

Figure 1. Flow diagram for inclusion and exclusion of knees. GAE, genicular artery embolization; TKA, total knee arthroplasty.

The WOMAC questionnaire was applied in person or via phone contact[14] during the follow-up. Patient-perceived satisfaction with GAE was assessed using an investigator-designed four-category ordinal scale: very satisfied, satisfied, dissatisfied, or very dissatisfied. The scale was intentionally kept as simple as possible to minimize respondent burden and facilitate comprehension among patients with diverse educational and health-literacy backgrounds. Technical success was defined as successful embolization of at least one genicular artery. Clinical success was defined as improvement in pain of ≥ 2 points and a reduction in WOMAC score meeting the minimally important difference (MID) threshold of 12 points.[15,16] Recurrence was defined as pain returning to baseline level after initial pain alleviation.

Patient characteristics, such as sex, age, body mass index, and Kellgren–Lawrence (KL) score, and procedural details, including the embolized arteries and their number, the total amount of embolic agent used, and pattern of periarticular vascular blush, were reviewed retrospectively from the hospital electronic medical record system and procedural imaging. Follow-up assessments were based on the most recent patient contact.

Periarticular vascular blush was graded as follows: grade 1–blush less than the background soft-tissue staining; grade 2–blush equal in intensity to the background soft-tissue staining; and grade 3–blush greater than the background soft-tissue staining. This grading was performed on DSA images obtained at the beginning of the procedure after contrast injection through a 4F diagnostic Cobra catheter (Cordis Medical, Miami Lakes, FL, USA) positioned approximately in the mid-portion of the femoral artery (Figure 2). Grading was based on images obtained from femoral artery contrast injection rather than on images acquired after superselective genicular artery contrast injection. This approach was preferred to allow comparison of periarticular vascular blush with the surrounding soft-tissue staining, thereby providing a more objective grading system, because on superselective genicular artery images even normal staining may be misinterpreted as hypervascular blush, and no surrounding staining is available for comparison to support objective grading.

Periarticular vascular grading was independently performed by two radiologists, one of whom had not participated in any of the GAE procedures. In cases of disagreement between the two readers, the final decision was made by a senior interventional radiologist.

Genicular artery embolization procedure

Before each procedure, informed consent was obtained from the patients, including off-label use of imipenem–cilastatin (IPM/CS) as an embolic agent. The most prominent pain location was marked with an electrocardiogram (ECG) electrode. Vascular access was obtained using a 4F vascular sheath in the ipsilateral femoral artery via an antegrade approach. When the antegrade approach was not possible due to an abdominal pannus, contralateral femoral artery access was obtained via a retrograde approach. After a 4F diagnostic Cobra catheter (Cordis Medical) was positioned approximately in the mid femoral artery, DSA images of the knee and surrounding tissues were acquired. Genicular arteries were identified on these images. Embolization of the genicular arteries supplying the symptomatic site marked with the ECG electrode was prioritized. However, all angiographically apparent genicular arteries contributing to the periarticular hypervascular blush were embolized, regardless of whether they arose ipsilateral or contralateral to the symptomatic side. In all cases, embolization was performed using 0.5 g IPM/CS after superselective catheterization with a 2.0F Progreat® microcatheter (Terumo Medical). The lyophilized IPM/CS powder was suspended in 10 mL of iodinated contrast medium before embolization. Embolization was performed in 0.2–0.3 mL increments of the IPM/CS suspension. Embolization was deemed successful when the hypervascular blush had completely disappeared while preserving parent artery patency (pruning). In Figure 3, angiographic images obtained before and after GAE demonstrate a marked reduction in periarticular vascular blush following embolization. The total amount of embolic agent used was recorded at the end of the procedure. Hemostasis was achieved with manual compression at the arterial access site, and patients were observed for ≥ 4 hours after treatment.

Statistical analysis

Statistical analysis was performed with SPSS 25 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $P < 0.05$. Continuous variables were presented as mean ± standard deviation or median (interquartile range) and categorical variables as frequencies and percentages. Continuous variables were assessed for normality (Shapiro–Wilk test), and comparisons were performed using appropriate parametric (paired-samples t-test/independent-samples t-test) or non-parametric (Wilcoxon signed-rank or Mann–Whitney U) tests according to data distribution. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. For periarticular vascular grading, inter-reader agreement between two readers was evaluated using linearly weighted Cohen's kappa, as the grading system was ordinal.

Kaplan–Meier survival analysis with the log-rank test was employed to assess the association between embolic material volume and recurrence-free survival after dichotomizing the embolic material volume as > 3.5 mL or ≤ 3.5 mL. The association between embolic material volume, modeled as a continuous variable, and recurrence hazard was evaluated using Cox proportional hazards regression analysis.

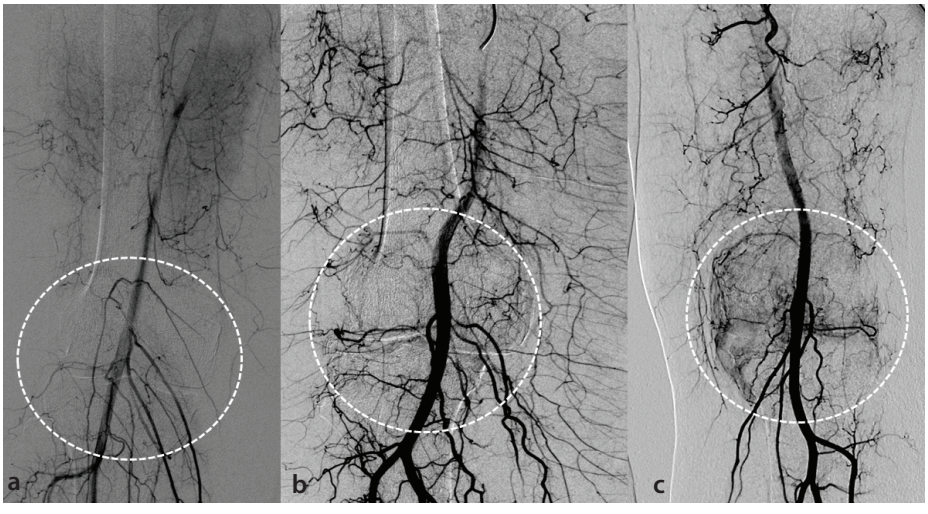

Figure 2. Periarticular vascular blush grading on angiography: **a)** grade 1–periarticular vascular blush is less than background surrounding soft tissue stain; **b)** grade 2–periarticular vascular blush is equal to background surrounding soft tissue stain; **c)** grade 3–periarticular vascular blush is greater than background surrounding soft tissue stain

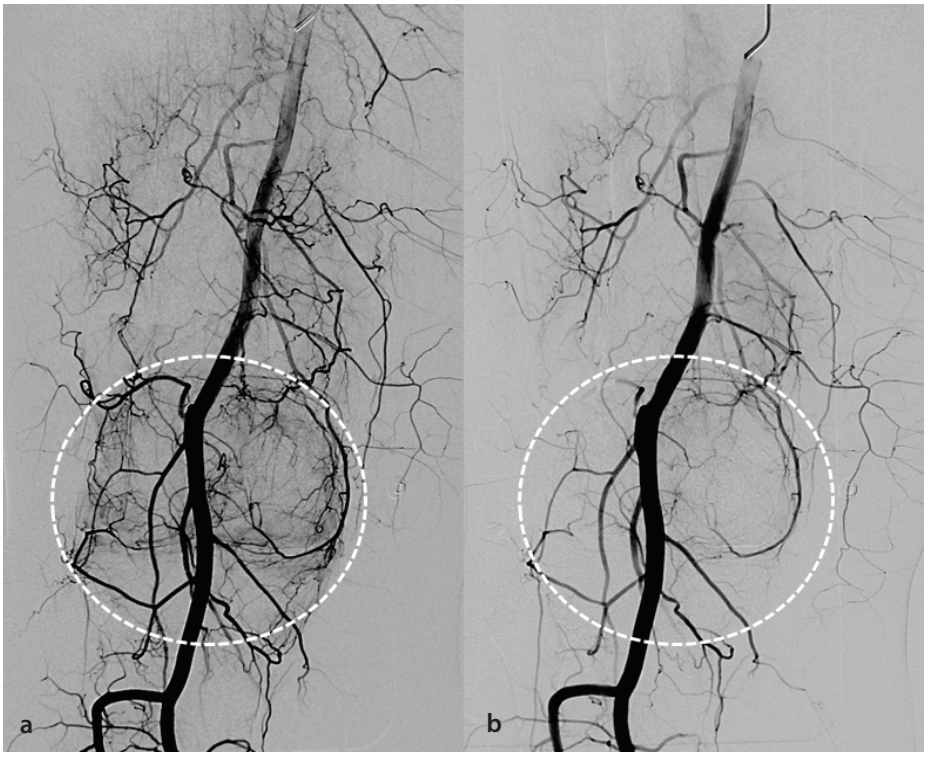

Figure 3. Representative angiographic images before **(a)** and after **(b)** genicular artery embolization demonstrate a marked reduction in periarticular vascular blush following treatment.

Results

Overall, 38 knees were treated during the study period. Twelve of the 38 were excluded from the study. This study included 24 patients (16 women, 66.7%) with 26 knees that underwent GAE for OA-related pain. The mean age was 63.2 ± 10.3 years. Patients and procedure characteristics are listed in Table 1. Technical success was achieved in all patients. The mean follow-up time was 11 ± 5.5 months. The mean decreases in NRS and WOMAC scores after GAE were 4.1 ± 2.8 and 21.3 ± 16.9, respectively. The overall clinical success rate was 73.1% [95% confidence interval (CI): 52.2%–88.4%]. For primary OA, the clinical success rate was 85% (95% CI: 62.1%–96.8%). For secondary OA, the clinical success rate was 33.3% (95% CI: 4.3%–77.7%). Seventeen treated knees (65.4%) were reported to have some level of satisfaction with GAE treatment, including 8 (30.8%) rated as very satisfied and 9 (34.6%) as satisfied. Satisfaction was significantly associated with clinical success ($P < 0.01$). Among the 17 treated knees with reported satisfaction, only 1 (5.9%) did not achieve clinical success. In contrast, among the 9 treated knees without satisfaction, 3 (33.3%) achieved clinical success.

Three knees (11.5%) were graded as 1, 7 (26.9%) as 2, and 16 (61.5%) as 3 according to the periarticular vascular blush grading. Inter-reader agreement was good (weighted Cohen's κ: 0.72; 95% CI: 0.49–0.94), with an agreement of 80.8%. There was no significant association between periarticular hypervascularity grade and KL grade ($P = 0.94$).

Eight knees (30.8%) experienced recurrence during the follow-up. The mean time to recurrence was 6.9 ± 5.8 months. Table 2 shows univariate analysis of variables between knees with and without recurrence. A lower total amount of embolic agent used was associated with recurrence with the independent-samples t-test ($P = 0.02$). Kaplan–Meier analysis demonstrated significantly longer recurrence-free survival among knees that received > 3.5 mL of embolic material ($P = 0.02$). However, total embolic volume was not significantly associated with recurrence hazard when modeled as a continuous variable in Cox regression ($P = 0.22$).

Periarticular vascular grade was not related to recurrence or clinical success rates ($P = 0.66$ for both). However, compared with knees with grade 1–2 periarticular vascularity, knees with grade 3 vascularity required embolization of significantly more genicular arteries and a greater volume of embolic agent (2.8 ± 1.2 mL vs. 1.6 ± 0.8 mL, $P = 0.02$; and 4.2 ± 2.7 mL vs. 1.9 ± 1.7 mL, $P = 0.02$, respectively).

Table 1. Patients and procedure characteristics

Characteristics	Total n = 26
Age (year), mean ± SD	63.2 ± 10.3
BMI (kg/m^2), median [IQR]	28.5 [25.5–32.4]
OA type, n (%)	
Primary OA	20 (76.9%)
Secondary OA*	6 (23.1%)
Side, n (%)	
Right	17 (65.4%)
Left	9 (34.6%)
Most prominent pain location, n (%)	
Medial	15 (57.7%)
Lateral	8 (30.8%)
Midline	3 (11.5%)
KL score, n (%)	
KL 1	3 (11.5%)
KL 2	9 (34.6%)
KL 3	12 (46.2%)
KL 4	2 (7.7%)
Periarticular vascular grade, n (%)	
Grade 1–2**	10 (38.5%)
Grade 3	16 (61.5%)
Embolized genicular arteries, n (%)***	
DGA	14 (23.3%)
SMGA	10 (16.7%)
SLGA	15 (25%)
IMGA	6 (10%)
ILGA	15 (25%)
Number of embolized arteries, median [IQR]	2.0 [1.0–3.0]
Total embolic agent used (mL), mean ± SD	3.4 ± 2.6

*2 trauma related secondary OA and 4 inflammatory arthritis (2 ankylosing spondylitis, 1 ANCA-associated vasculitis, 1 Sjogren's syndrome) related secondary OA.
**3 knees with grade 1 and 7 knees with grade 2.
***Percentages are calculated using the total number of embolized arteries as the denominator.
BMI, body mass index; IQR, interquartile range; OA, osteoarthritis; SD, standard deviation; KL, Kellgren–Lawrence; DGA, descending genicular artery; ILGA, inferior lateral genicular artery; IMGA, inferior medial genicular artery; SLGA, superior lateral genicular artery; SMGA, superior medial genicular artery.

All patients experienced skin discoloration in the early post-procedural period, which resolved within hours after GAE. One patient developed minor skin ulceration, which healed spontaneously without treatment (mild adverse event). No moderate/severe or permanent complications were observed in this study.

Table 2. Comparison of knees with and without recurrence

Variable	No recurrence (n = 18)	Recurrence (n = 8)	*P* value
Age (year), mean ± SD	64.4 ± 9.1	60.6 ± 12.9	0.39
BMI (kg/m^2), median [IQR]	29.1 [24.9–33.5]	28.4 [25.9–31.8]	0.69
Total embolic agent used (mL), mean ± SD	4 ± 2.8	2 ± 1.1	0.02*
Number of embolized arteries, median (IQR)	2.0 (2.0–3.0)	1.0 (1.0–3.25)	0.31
Sex, n (%)			1.00
Female	12 (66.7%)	5 (62.5%)	
Male	6 (33.3%)	3 (37.5%)	
OA type, n (%)			1.00
Primary OA	14 (77.8%)	6 (75%)	
Secondary OA	4 (22.2%)	2 (25%)	
KL score, n (%)			0.40
KL 1–2	7 (38.9%)	5 (62.5%)	
KL 3–4	11 (61.1%)	3 (37.5%)	
Periarticular vascular grade, n (%)			0.66
Grade 1–2†	6 (33.3%)	4 (50.0%)	
Grade 3	12 (66.7%)	4 (50.0%)	

*Mean difference, 2.0 mL; 95% CI, 0.4–3.6 mL; effect size (Hedges' g) = 0.8.
†3 knees with grade 1 and 7 knees with grade 2.
BMI, body mass index; IQR, interquartile range; OA, osteoarthritis; SD, standard deviation; KL, Kellgren–Lawrence; CI, confidence interval.

Discussion

In this study, consistent with the existing literature, GAE was associated with pain reduction and functional improvement after treatment.[6,8,17-19] The overall clinical success rate was 73.1%. Clinical success was less favorable in patients with secondary OA, with a clinical success rate of 33.3%. GAE was not associated with a higher complication rate in the secondary OA subgroup. No severe or permanent complications were observed, and no patients reported symptoms worsening after GAE. Further evaluation of GAE outcomes in secondary OA remains important, given that an increase in complications or post-procedural symptom exacerbation was not observed in this study. The primary rationale for including knees with secondary OA was not to compare clinical success rates between primary and secondary OA, as the pathophysiology of synovitis may differ substantially across etiologies, including within the secondary OA subgroup. Rather, the study aimed to demonstrate that GAE can be performed in patients with secondary OA without an apparent increase in complication rates. Detailed clinical information about knees with inflammatory arthritis is presented in Supplementary File 1.

Among the nine knees for which patients reported dissatisfaction with the treatment, 3 (33.3%) of them met clinical success criteria. This may reflect high patient expectations, underscoring the importance of pre-procedural counseling to clarify that the primary goal of treatment is to control OA-related symptoms and improve function, rather than to guarantee their complete resolution. Alternatively, this finding may suggest that more stringent criteria for defining clinical success are needed. Although clinical success was defined as an improvement of ≥ 2 points in the NRS along with an improvement in the WOMAC score, the clinical success group demonstrated a much higher mean pre-to-post-procedural NRS reduction of 5.4 ± 1.9 points in this study. Another less-studied topic in the GAE literature is symptom recurrence and its potential predictors after treatment. Importantly, some GAE studies do not explicitly report whether patients experienced recurrence or required repeat intervention.[6,8,20] A study,[12] however, reported that 60% of their patients underwent repeated GAE in the long term. In this study, the recurrence rate was 30.8% at a mean follow-up of 11 ± 5.5 months. In the univariable comparison, knees with recurrence received a lower mean embolic volume than those without recurrence. In univariable survival analysis, an embolic volume > 3.5 mL was associated with longer recurrence-free survival; however, embolic volume was not significantly associated with recurrence hazard when analyzed as a continuous variable using Cox regression. However, these results may reflect a non-linear, threshold-type association; as this study has a limited number of recurrence events, this finding should be interpreted as exploratory and hypothesis-generating.

A possible explanation for the association between recurrence and embolic volume is that a higher embolic volume may enable more complete devascularization of the abnormal hypervascular blush, potentially improving control of pain-related neovascularity. The proposed mechanism underlying this effect may be related to the periarticular anastomotic network. A study[21] evaluated the importance of this network and showed that retrograde GAE (R-GAE) is a safe and feasible catheterization route with potential early efficacy. Perfusion territories accessed via R-GAE may, however, differ from those reached with antegrade GAE, underscoring the hemodynamic impact of genicular anastomoses. Consistent with this concept, we have observed that continuing IPM/CS embolization beyond the point of initial angiographic pruning can unmask collateral/anastomotic filling between genicular arteries, allowing embolic material to reach hypervascular regions retrogradely that may not be opacified—or adequately treated—during the initial antegrade run. Accordingly, when a collateral/anastomotic pathway is identified during GAE, embolization of the collateral/anastomotic pathway with IPM/CS may be considered by advancing the microcatheter further into the genicular artery and/or by using a controlled injection with gradually increasing pressure under continuous flu-

oroscopic monitoring (Supplementary File 2). Amin et al.[10] found no link between permanent embolic agent volume and clinical response and instead pointed to reperfusion of treated vessels as the cause of recurrence. The discrepancy between their findings and those of the present study may be related, at least in part, to differences in embolic agent type. In musculoskeletal embolization, IPM/CS may not only act as a temporary embolic agent but may also have potential anti-inflammatory and analgesic effects and may preferentially affect inflammation-associated neovascularity.[22-25]

Defining the embolic endpoint of GAE as angiographic pruning is inherently subjective and remains controversial in the literature.[26,27] This subjectivity may also apply within a single center when procedures are performed by multiple operators, as in the present study. Although no significant differences were observed among operators in recurrence rates or in the number of embolized arteries, total embolic volume differed significantly, with one operator using greater volumes than the others. This difference may not necessarily reflect differences in procedural technique, as all three operators were in close communication and followed similar procedural principles. Rather, it may be attributable to the adoption of continued embolization beyond the point of initial pruning in later cases, most of which were performed by the operator who used higher embolic volumes.

Taheri Amin et al.[26] attempted to establish more objective criteria for pruning by quantifying blush size before and after embolization and calculating the blush reduction ratio. Although that study showed that reaching a defined pruning endpoint led to significant NRS improvement, baseline blush size or blush reduction alone did not predict clinical response. Similarly, although the periarticular hypervascularity grading system in our study was based on intensity rather than size, no significant relationship was observed between periarticular vascular grading and clinical response.

Three of the eight patients with recurrence underwent a second GAE procedure. Knee vascular grading at the second procedures (two grade 3 and one grade 2) was the same as at the first procedures in all three patients. The mean embolic volume used during the second procedures was 2.8 ± 2.1 mL higher than that used during the initial sessions. The higher embolic volume required during the second GAE procedures, despite similar vascular grades, was likely related to additional attempts to embolize relevant collateral pathways. In these repeat procedures, embolization was extended beyond the initially treated territory when collateral filling was identified, resulting in greater embolic volume use. All three patients reported more pronounced pain relief and greater satisfaction in the short term (at 1 month) with the second procedures compared with the first procedures.

A study[28] graded angiographic vascularity of the Achilles tendon during transcatheter arterial microembolization for refractory Achilles tendinopathy as absent, minimal, moderate, or massive. Grading angiographic vascularity in such a manner is quite subjective; the higher-vascularity group (grade 2–3) demonstrated greater clinical success (92.2% vs. 64.5%) when they dichotomized the grading (grade 2–3 vs. grade ≤ 1). An angiographic vascularity grading system specifically developed for or applied to GAE seems to be missing. In this study, periarticular vascular blush was graded into three grades. To provide a more objective assessment, the intensity of periarticular knee vascular blush was compared with the background staining of the surrounding soft tissues. Knees treated with GAE for indications other than OA-related pain, including hemarthrosis control and post-TKA pain, were excluded, as these conditions are more likely to demonstrate more intense periarticular blush and could therefore skew the grading system.

No significant association was found between vascularity grade (grades 1–2 vs. grade 3) and either clinical success or recurrence. However, knees with grade 3 vascularity required embolization of significantly more genicular arteries and a greater volume of embolic agent than those with grades 1–2 vascularity. These findings suggest that, to adequately control more severe periarticular hypervascularity, embolization of additional genicular arteries and administration of a larger volume of embolic agent may be necessary. This is consistent with the findings of Taheri Amin et al.,[26] who reported that a higher embolic volume was required in cases with larger hyperemic blush size to achieve the same embolic endpoint. In contrast to the study by Amin et al.,[10] however, no significant association between KL grade and periarticular hypervascularity grade was observed in the present study. In their study, the difference in blush size across KL grades was driven primarily by KL grade 4 knees, which had the largest blush size among KL grades. However, only two KL grade 4 knees were included in the present study. This, together with the relatively small sample size, may have limited the ability to detect a relationship between periarticular vascularity grade and KL grade, if such a relationship truly exists. Another concern regarding the size-based grading proposed by Taheri Amin et al.,[26] compared with the intensity-based grading employed in our study, is that size-based grading may not clearly distinguish whether the entire blush supplied by an embolized artery represents pathologic hypervascularity or includes normal periarticular staining of the knee.

This study has multiple limitations. The relatively small overall sample size, limited number of recurrence events, and variable follow-up durations reduced the precision and statistical power of the recurrence predictor analyses. Therefore, these findings should be interpreted with caution and should not be regarded as definitive evidence of independent predictors of recurrence. Second, the proposed grading system lacks external validation. One of the readers who performed vascular grading had participated in the clinical follow-up of the patients and was therefore not formally blinded to clinical outcomes, although outcome data were not readily available during the grading session.

Third, the angiographic images used for vascularity grading were not standardized. Variations in injection pressure, catheter position, contrast medium concentration, and the number of frames acquired in the overview series may influence the apparent intensity of the angiographic blush. Nevertheless, the present dataset reflects real-world clinical practice and the routine technical variability encountered during GAE procedures.

In addition, although embolization was continued beyond the point of initial angiographic pruning, an increased rate of clinical complications was not observed; however, post-procedure magnetic resonance imaging was not routinely performed, and radiologic complications (e.g., osteonecrosis) may therefore have been underdetected. Notably, GAE-related osteonecrosis has only been reported following the use of permanent embolic agents. To the best of our knowledge, no cases of osteonecrosis after GAE performed with IPM/CS have been reported in the literature to date.[29]

Nevertheless, our results may aid patient selection for GAE, provide insight into the potential mechanisms underlying symptom

recurrence, and guide future studies investigating its possible causes.

GAE was safe and effective, with an acceptable patient satisfaction rate in controlling OA-related symptoms, although outcomes were less favorable in secondary OA. Higher IPM/CS volume was associated with a lower observed recurrence rate, without an apparent increase in clinical complications. However, given the limited overall sample size and small number of recurrence events, this association should be interpreted as hypothesis-generating rather than as evidence of an independent predictor of recurrence.

Acknowledgements

The authors used generative artificial intelligence tools during the preparation of this manuscript solely for language editing, including improvement of grammar, clarity, and overall coherence. Following this assistance, the authors carefully reviewed and revised the manuscript and take full responsibility for the accuracy and integrity of its content.

Footnotes

Conflict of interest disclosure

The authors declared no conflicts of interest.

Supplementary File 1: https://d2v96fxpocvxx.cloudfront.net/beb8919b-f013-4ea1-b1c8-40332e840fe1/content-images/5335921b-7ebf-48dd-a16f-b608a236334e.pdf

Supplementary File 2: https://d2v96fxpocvxx.cloudfront.net/830ebeaf-3f7e-42af-bd4b-fde69d6bc084/documents/Supplementary%20File%202.pptx

References

1. Duong V, Oo WM, Ding C, Culvenor AG, Hunter DJ. Evaluation and treatment of knee pain: a review. *JAMA*. 2023;330(16):1568-1580. [Crossref]
2. Castro-Domínguez F, Vargas-Negrín F, Pérez C, Gutiérrez-Prieto H, Rebollo P. Unmet needs in the osteoarthritis chronic moderate to severe pain management in Spain: a real word data study. *Rheumatol Ther*. 2021;8(3):1113-1127. [Crossref]
3. Dainese P, Wyngaert KV, De Mits S, Wittoek R, Van Ginckel A, Calders P. Association between knee inflammation and knee pain in patients with knee osteoarthritis: a systematic review. *Osteoarthritis Cartilage*. 2022;30(4):516-534. [Crossref]
4. Heller DB, Beggin AE, Lam AH, Kohi MP, Heller MB. Geniculate artery embolization: role in knee hemarthrosis and osteoarthritis. *Radiographics*. 2022;42(1):289-301. [Crossref]
5. Ro DH, Jang MJ, Koh J, et al. Mechanism of action of genicular artery embolization in a rabbit model of knee osteoarthritis. *Eur Radiol*. 2023;33(1):125-134. [Crossref]
6. Berreta RS, Rubin J, Manivannan A, et al. Geniculate artery embolization for the treatment of mild to moderate knee osteoarthritis improves pain and function at short-term follow-up with significant procedural heterogeneity described across the literature: a systematic review. *Arthroscopy*. 2025;41(6):2117-2133. [Crossref]
7. Cusumano LR, Sparks HD, Masterson KE, Genshaft SJ, Plotnik AN, Padia SA. Genicular artery embolization for treatment of symptomatic knee osteoarthritis: 2-year outcomes from a prospective IDE trial. *J Vasc Interv Radiol*. 2024;35(12):1768-1775. [Crossref]
8. Epelboym Y, Mandell JC, Collins JE, et al. Genicular artery embolization as a treatment for osteoarthritis related knee pain: a systematic review and meta-analysis. *Cardiovasc Intervent Radiol.* 2023;46(6):760-769. [Crossref]
9. Taslakian B, Miller LE, Mabud TS, et al. Genicular artery embolization for treatment of knee osteoarthritis pain: systematic review and meta-analysis. *Osteoarthr Cartil Open*. 2023;5(2):100342. [Crossref]
10. Amin AT, Hübner A, Abu-Gharbieh L, et al. Repeated genicular artery embolization using permanent microspheres for severe osteoarthritis and postsurgical pain. *Cardiovasc Intervent Radiol.* 2026;49(7):1370-1381. [Crossref]
11. Okuno Y, Korchi AM, Shinjo T, Kato S, Kaneko T. Midterm clinical outcomes and MR imaging changes after transcatheter arterial embolization as a treatment for mild to moderate radiographic knee osteoarthritis resistant to conservative treatment. *J Vasc Interv Radiol*. 2017;28(7):995-1002. [Crossref]
12. Landers S, Hely R, Page R, et al. Genicular artery embolization to improve pain and function in early-stage knee osteoarthritis-24-month pilot study results. *J Vasc Interv Radiol.* 2020;31(9):1453-1458. [Crossref]
13. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. *J Rheumatol.* 1988;15(12):1833-1840. [Crossref]
14. Bellamy N, Wilson C, Hendrikz J, et al. Osteoarthritis Index delivered by mobile phone (m-WOMAC) is valid, reliable, and responsive. *J Clin Epidemiol*. 2011;64(2):182-190. [Crossref]
15. Devji T, Guyatt GH, Lytvyn L, et al. Application of minimal important differences in degenerative knee disease outcomes: a systematic review and case study to inform *BMJ* Rapid Recommendations. *BMJ Open*. 2017;7(5):e015587. [Crossref]
16. Tubach F, Ravaud P, Baron G, et al. Evaluation of clinically relevant changes in patient reported outcomes in knee and hip osteoarthritis: the minimal clinically important improvement. *Ann Rheum Dis*. 2005;64(1):29-33. [Crossref]
17. Bagla S, Piechowiak R, Sajan A, Orlando J, Hartman T, Isaacson A. Multicenter randomized sham controlled study of genicular artery embolization for knee pain secondary to osteoarthritis. *J Vasc Interv Radiol*. 2022;33(1):2-10.e2. [Crossref]
18. Ciaffi J, Papalexis N, Vanni E, et al. Minimally invasive interventional procedures for osteoarthritis and inflammatory arthritis: a systematic review and meta-analysis. *Semin Arthritis Rheum*. 2024;68:152525. [Crossref]
19. Lee L, Epelboym Y. Review of genicular artery embolization, radiofrequency ablation, and cryoneurolysis in the management of osteoarthritis-related knee pain. *Diagn Interv Radiol*. 2023;29(4):614-620. [Crossref]
20. Callese T, Cusumano LR, Sparks H, et al. Early intervention in knee osteoarthritis with genicular artery embolization is associated with improved clinical outcomes. *Eur Radiol*. 2025;35(12):7617-7626. [Crossref]
21. Amin AT, Ziayee F, Boschheidgen M, et al. Road to genicular artery embolization: importance of the anastomotic network. *Cardiovasc Intervent Radiol*. 2025;48(12):1801-1815. [Crossref]
22. Nakamura H, Yamamoto A, Watanabe H, et al. Microembolization effects of imipenem/cilastatin in vivo depicted by monochromatic synchrotron X-ray microangiography. *J Vasc Interv Radiol*. 2025;36(2):340-346. [Crossref]
23. Koucheki R, Dowling KI, Patel NR, Matsuura N, Mafeld S. Characteristics of imipenem/cilastatin: considerations for musculoskeletal embolotherapy. *J Vasc Interv Radiol*. 2021;32(7):1040-1043.e1. [Crossref]
24. Yamada K, Jahangiri Y, Li J, et al. Embolic characteristics of imipenem-cilastatin particles in vitro and in vivo: implications for transarterial embolization in joint arthropathies. *J Vasc Interv Radiol.* 2021;32(7):1031-1039.e2. [Crossref]
25. Matsuyama Y, Yamanaka M, Taniguchi W, et al. Analgesic effects of intraarterial injection of imipenem/cilastatin sodium in a rat model of knee osteoarthritis. *Neuroscience*. 2025;575:122-130. [Crossref]
26. Taheri Amin A, Kemmer E, Hübner AJ, et al. Segmentation of blush size guides embolic

endpoints in genicular artery embolization. *Eur Radiol*. 2026;36(7):5895-5906. [Crossref]

27. Ahmed O, Epelboym Y, Haskal ZJ, et al. Society of Interventional Radiology Research Reporting Standards for Genicular Artery Embolization. *J Vasc Interv Radiol*. 2024;35(8):1097-1103. [Crossref]

28. Sugihara E, Bhatia A, Shibuya M, et al. A retrospective, multicentric evaluation of the safety and efficacy of transcatheter arterial micro embolization for refractory Achilles tendinopathy. *Cardiovasc Intervent Radiol*. 2025;48(12):1725-1734. [Crossref]

29. Lanza E, Poretti D, Pedicini V, Kon E, Laghi A. Permanent vs. temporary embolic agents in genicular artery embolization for knee osteoarthritis: a systematic review and meta-analysis. *Eur J Radiol*. 2026;202:112968. [Crossref]