Current Practice of Autologous Minced Cartilage Implantation for Articular Cartilage Defects of the Knee – A Cross-Sectional Analysis Based on the German Cartilage Registry (KnorpelRegister DGOU)

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Background: Autologous minced cartilage (MC) is a promising one-stage procedure for treating full-thickness articular cartilage defects of the knee. Although its clinical use has increased in recent years, its precise indications and limitations remain incompletely defined.

Objective: To evaluate real-world utilization patterns of MC compared with established cartilage regeneration procedures using data from the German Cartilage Registry (KnorpelRegister DGOU).

Methods: Between January 2021 and December 2025, 1,767 patients treated with arthroscopic bone marrow stimulation (BMS; n = 268), autologous chondrocyte implantation (ACI; n = 1,076), matrix-augmented bone marrow stimulation (mBMS; n = 150), or MC (n = 273) were analyzed. Groups were compared regarding patient characteristics (age, sex, and previous surgeries), defect characteristics (size, location, etiology, and grade), and concomitant surgical procedures.

Results: MC was predominantly used for small-to-medium-sized defects (mean size, 2.52 cm²; SD, 1.57). Defects treated with MC were significantly smaller than those treated with ACI (mean size, 4.05 cm²; SD, 1.60; $p < 0.01$) and comparable in size to those treated with BMS and mBMS. The proportion of trochlear defects was highest in the MC group (30.5%). Concomitant surgical procedures were significantly less frequent in patients undergoing MC than in those undergoing ACI or BMS (both $p < 0.01$), with no significant difference compared with mBMS.

Conclusion: Within the German Cartilage Registry, MC was predominantly used for small-to-medium-sized articular cartilage defects, consistent with current expert recommendations. The lower frequency of concomitant procedures warrants further investigation, given the importance of addressing concomitant pathologies during cartilage repair. Long-term outcome data and prospective comparative studies are needed to refine indications and support broader standardization.

What this study adds to existing knowledge: This registry analysis characterizes the real-world use of MC, showing its predominant application in small-to-medium-sized defects and a lower frequency of concomitant procedures than with ACI or BMS.

How this study might affect research, practice, or policy: These findings support further evaluation of procedure selection and concomitant pathology management and highlight the need for prospective comparative studies with long-term follow-up.

Study Design: Retrospective comparative analysis of prospectively collected registry data.

Level of Evidence: Registry Study, Case Series Level IV

Keywords: Cartilage regeneration; Knee; Minced cartilage; Autologous chondrocyte implantation; Registry; Bone marrow stimulation

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Introduction

Focal articular cartilage defects of the knee represent a clinically significant challenge, affecting patients across a wide age spectrum and carrying substantial risks of functional impairment and progression to osteoarthritis if left untreated [1][2]. Established cartilage regeneration strategies include arthroscopic bone marrow stimulation (BMS), matrix-augmented bone marrow stimulation (mBMS/AMIC), osteochondral autograft transplantation (OAT), and autologous chondrocyte implantation (ACI) - each associated with distinct indications, technical requirements, and evidence profiles [1][2]. Long-term data from randomized controlled trials and prospective cohort studies confirm that restorative procedures (ACI, OAT) yield superior durability compared to reparative approaches (BMS) for medium-to-large defects in younger active patients [1][3][4].

Autologous minced cartilage (MC) implantation was first described by Albrecht et al. in the 1980s as a conceptually simple one-stage approach exploiting the regenerative capacity of resident chondrocytes within minced autologous cartilage fragments [5]. The procedure involves harvesting cartilage from a non-weight-bearing area or the defect rim, mechanically mincing the tissue into small fragments (typically 0.5–1 mm), and implanting these fragments into the prepared defect, typically secured with a collagen matrix or biological adhesive. Preclinical studies have demonstrated chondrocyte migration and extracellular matrix formation from minced fragments, supporting the biological plausibility of this approach.

Despite its early description, MC attracted limited clinical attention for several decades. Renewed interest emerged following technical refinements, including the introduction of acellular collagen matrices and, more recently, arthroscopic shaver-based mincing systems combined with autologous plasma and thrombin [6][7]. These innovations substantially lowered the technical barrier to MC, enabling fully arthroscopic one-stage application. However, chondrocyte viability following high-speed shaver-based mincing remains a subject of scientific debate, raising questions about whether the mechanism of action is primarily cell-mediated or relies on bioactive matrix components and growth factor release.

Clinical evidence for MC is accumulating but remains limited relative to established procedures. A meta-analysis by Frodl et al. identified 295 patients across nine studies, demonstrating proof-of-principle efficacy but insufficient data to define specific indications or limitations. Runer et al. (2023) reported the first minimum five-year follow-up data for MC, demonstrating sustained clinical improvements and a low revision rate of 3.5% at a mean follow-up of 65.5 months [8]. Schneider et al. (2024) prospectively followed 62 patients after standardized arthroscopic MC and observed significant KOOS and pain improvements at 24 months with a revision rate of 8.1% [6]. Blanke et al. (2024) reported significant clinical and MRI improvements in 71 patients treated with PRP/fibrin-augmented MC at 12–24 months [7]. Comparative data suggest that MC may achieve outcomes comparable to ACI in matched-pair analyses for selected indications [9], while mBMS/AMIC has demonstrated superior outcomes compared to hand-minced cartilage in at least one matched cohort study [10].

Considering the limited but growing evidence base, the Expert Committee for Clinical Tissue Regeneration of the German Society for Orthopaedics and Trauma Surgery (DGOU) has recommended restricting MC indications to smaller, less demanding defects until further evidence is available [11]. Nevertheless, MC has gained increasing clinical traction in Germany and internationally, driven in part by its technical simplicity, one-stage nature, and the absence of the regulatory and cost barriers that affect ACI.

The present analysis aimed to evaluate how MC has been applied among cartilage regeneration centers contributing to the German Cartilage Registry (KnorpelRegister DGOU), hypothesizing that MC would be used for smaller defects compared to ACI but in a similar indication range as BMS and mBMS, and that patient and defect characteristics would differ meaningfully between treatment groups.

Methods

Study Design and Registry Description

This was a retrospective cross-sectional analysis of prospectively collected registry data from the German Cartilage Registry (KnorpelRegister DGOU). The registry is a nationwide, longitudinal, multicenter observational registry of patients undergoing surgical treatment for articular cartilage defects of the knee, ankle, and hip joints. It was initiated in 2013 by the Working Group for Clinical Tissue Regeneration of the German Society for Orthopaedics and Trauma Surgery (DGOU) and currently includes 125 participating sites. The registry is conducted in accordance with the Declaration of Helsinki, registered at the German Clinical Trials Register (DRKS00005617), and approved by the Ethics Commission of the Medical Center – University of Freiburg (EK-FR 105/13_130795).

The analysis period was defined as January 2021 to December 2025. This start date was selected to coincide with the first systematically documented MC procedures within the KnorpelRegister DGOU, ensuring a contemporaneous and methodologically consistent

comparison between all four treatment groups within an identical calendar period.

Patient Selection

All patients aged ≥18 years who underwent surgical treatment for articular cartilage defects of the knee with one of four index procedures - BMS, ACI, mBMS, or MC - between January 2021 and December 2025, and who provided signed written informed consent, were eligible for inclusion. Patients without a valid procedure code, incomplete baseline data, or prior enrollment for the same defect were excluded (**Figure 1**). Of 9,486 total knee patients enrolled in the registry by December 2025, 1,767 met the inclusion criteria for this analysis.

Data Collection

Patient and defect-specific data were recorded by the treating surgeon at the time of index surgery using the validated web-based electronic data capture system "RDE-Light" (Clinical Trials Unit, Freiburg), compliant with GAMP 5 and Good Clinical Practice (GCP) standards. Collected baseline parameters included: age, sex, body mass index (BMI), symptom duration (months), number of previous surgeries to the affected defect and knee, revision status, defect size (c m^2), defect grade (ICRS classification), defect etiology (traumatic, degenerative, post-traumatic, other including osteochondritis dissecans [OCD]), defect localization (patella, trochlea, medial femoral condyle [MFC], lateral femoral condyle [LFC], medial tibial plateau [MTP], lateral tibial plateau [LTP]), integrity of the corresponding joint surface, Kellgren-Lawrence grading on standing radiographs, number of treated defects, and concomitant surgical procedures performed.

Patient-reported outcome measures (PROMs) collected at follow-up (6, 12, 24, 36, and 60 months post-surgery) include the International Knee Documentation Committee score (IKDC), the Knee injury and Osteoarthritis Outcome Score (KOOS), and the visual analogue scale for pain (VAS). Given that only a minor proportion of MC patients had reached mid-term follow-up endpoints at the time of this analysis, outcome data were not included in the present cross-sectional comparison.

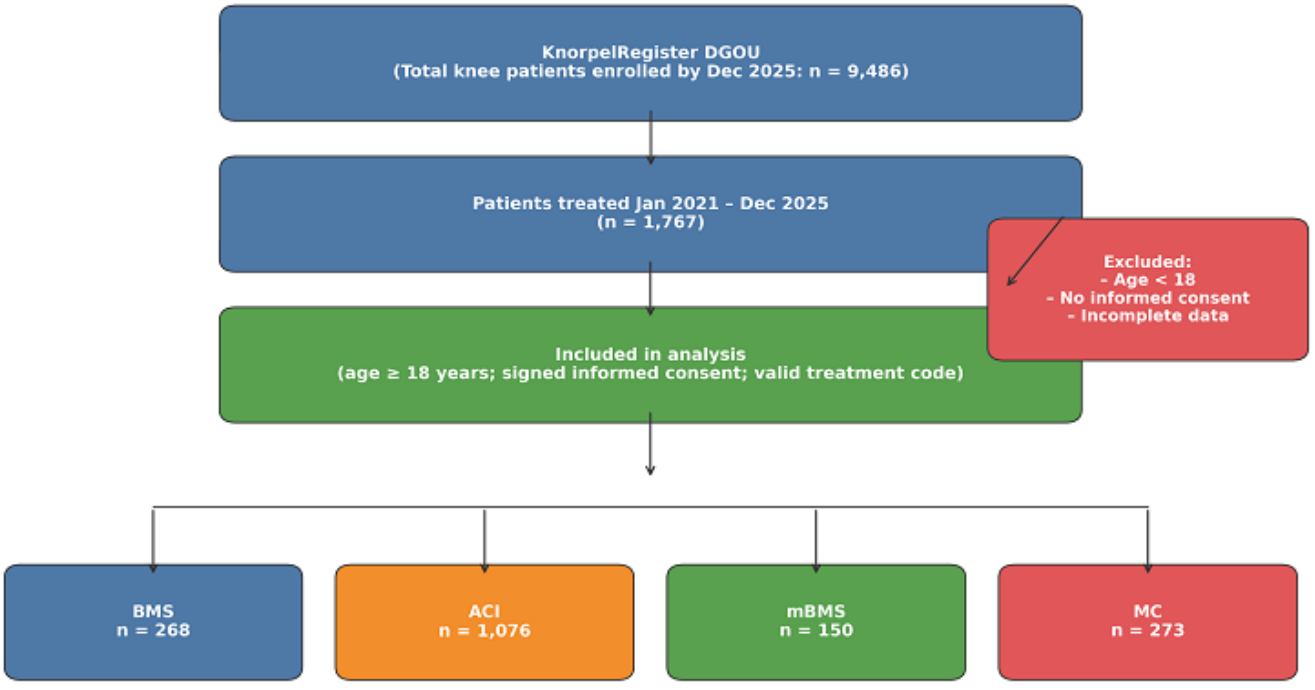

Figure 1. Patient inclusion flowchart. Schematic representation of the patient selection process from the KnorpelRegister DGOU for the present analysis.

Statistical Analysis

Statistical analysis was performed using SPSS version 29.0 (IBM Corp., Armonk, NY, USA). Normal distribution of continuous variables was assessed using the Shapiro-Wilk test, Kolmogorov-Smirnov test, and visual inspection of Q-Q plots. Given the large total sample size (n = 1,767), one-way analysis of variance (ANOVA) with post-hoc Tukey correction was applied for continuous variables to enable pairwise group comparisons while controlling the familywise error rate. Categorical variables were compared using the chi-squared test. Continuous data are reported as mean ± standard deviation (SD). Categorical data are reported as frequency and percentage. Statistical significance was

defined as $p < 0.05$ (two-tailed). All p-values are reported to three decimal places; values below 0.001 are reported as $p < 0.001$.

The absence of statistically significant differences in several baseline parameters (BMI, symptom duration, pre-operative PROMs) despite numerically visible differences reflects the wide within-group standard deviations combined with the post-hoc correction for multiple comparisons, which reduces power for individual pairwise contrasts. The substantially larger ACI group (n = 1,076) further affected the balance of group sizes, which can influence ANOVA sensitivity for smaller groups. These limitations are acknowledged in the Discussion.

Results

A total of 1,767 patients met the inclusion criteria and were analyzed: BMS (n = 268), ACI (n = 1,076), mBMS (n = 150), and MC (n = 273). The patient inclusion process is illustrated in **Figure 1**.

Patient and Defect Characteristics

The mean age differed substantially across groups, with BMS patients being notably older (49.22 ± 11.12 years) compared to ACI (34.84 ± 9.42 years), mBMS (38.59 ± 9.93 years), and MC (37.38 ± 11.04 years) (**Table 1, Figure 2**). Despite this clinically meaningful difference, statistical significance was not reached for all pairwise comparisons after Tukey correction, likely reflecting wide within-group variability and the effect of multiple comparison adjustment. BMI, symptom duration, pre-operative VAS, IKDC, and KOOS scores did not differ significantly between groups, indicating broadly comparable pre-operative functional impairment across all four treatment cohorts.

Defect Size

The most important finding was that ACI patients presented with significantly larger defect sizes (mean 4.05 ± 1.60 cm^2) compared to all other groups (BMS: 2.24 ± 1.95 cm^2; mBMS: 2.18 ± 1.48 cm^2; MC: 2.52 ± 1.57 cm^2; all $p < 0.01$) (**Figure 3**). Defect size in the MC group was comparable to BMS and mBMS and did not differ significantly from either. The majority of defects across all groups were ICRS grade IIIa/IIIb or grade IVa/IVb, indicating that predominantly full-thickness defects were treated across all modalities (**Table 2**).

Defect Localization

A notable finding was the distribution of defect localization (**Table 3, Figure 4**). The proportion of trochlear defects was highest in the MC group (30.5%) compared to BMS (15.0%), ACI (16.2%), and mBMS (22.8%). Patellar defects were most frequent in the ACI group (46.6%), while MFC defects predominated in the BMS group (48.3%). Differences in localization distribution were statistically significant (chi-squared test, $p < 0.01$).

Revision Status and Surgical History

ACI patients showed a substantially higher proportion of previous surgeries to both the affected defect (≥18.8% with ≥1 previous surgery) and the affected knee (71.4% with ≥1 previous surgery) compared to BMS (10.5%; 31.6%), mBMS (25.7%; 43.8%), and MC (15.2%; 34.7%), consistent with ACI being preferentially used in revision settings (**Table 2**). The proportion of revision procedures was correspondingly highest in ACI (62.2%) versus BMS (27.8%), mBMS (33.3%), and MC (28.4%).

Table 1. Patient and Defect Characteristics (Continuous Parameters) at Time of Surgery

Parameter	BMS (n=268)	ACI (n=1,076)	mBMS (n=150)	MC (n=273)	p-value
Age (years)	49.22 ± 11.12	34.84 ± 9.42	38.59 ± 9.93	37.38 ± 11.04	<0.01*
BMI	29.43 ± 5.74	26.52 ± 4.71	28.87 ± 13.85	27.45 ± 4.82	NS
Symptom duration (months)	10.13 ± 15.24	17.39 ± 21.23	13.84 ± 13.79	12.83 ± 16.29	NS
Defect size (cm^2)	2.24 ± 1.95	4.05 ± 1.60 *	2.18 ± 1.48	2.52 ± 1.57	<0.01*
Pain VAS (0–10)	4.16 ± 2.43	3.71 ± 2.26	3.53 ± 2.29	3.16 ± 2.18	NS
IKDC score (pre-op)	39.06 ± 15.55	41.12 ± 16.03	43.18 ± 17.86	40.80 ± 16.44	NS
KOOS overall (pre-op)	47.83 ± 17.97	54.41 ± 17.55	54.11 ± 17.04	52.15 ± 17.37	NS

Data presented as mean ± SD. * $p < 0.05$ (ANOVA with post-hoc Tukey correction). NS = not significant. BMS, bone marrow stimulation; ACI, autologous chondrocyte implantation; mBMS, matrix-augmented bone marrow stimulation; MC, minced cartilage; BMI, body mass index; VAS, visual analogue scale; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score.

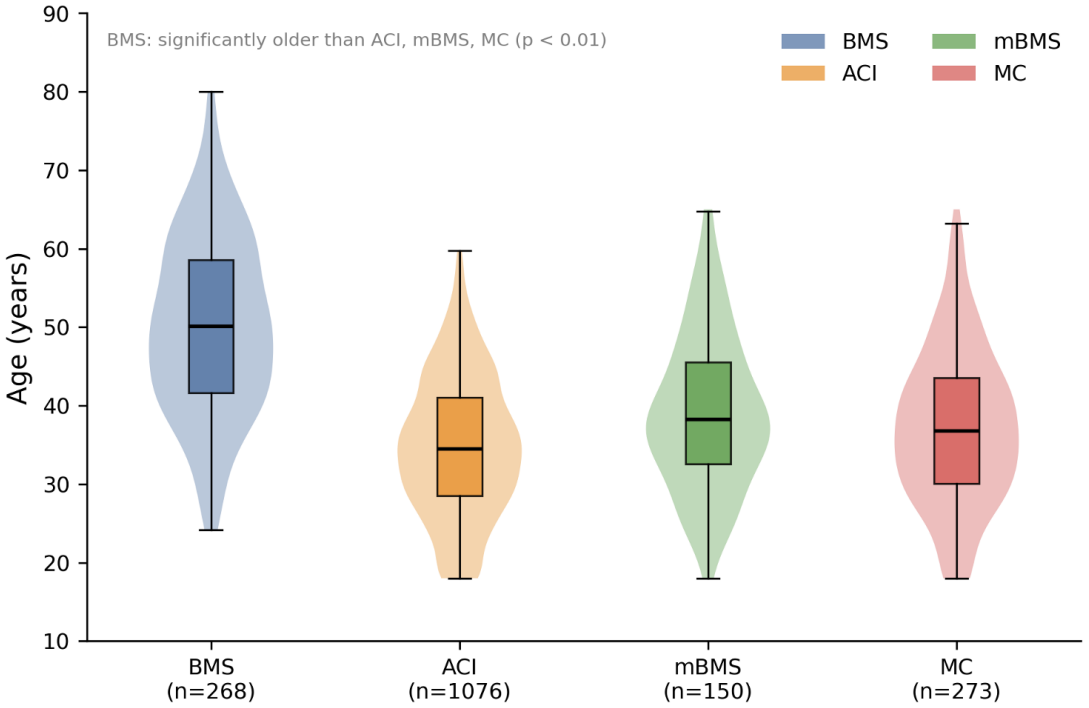

Figure 2. Age distribution by treatment modality. Violin plots with overlaid box-and-whisker plots. BMS patients were substantially older than patients in the other three groups. BMS patients were significantly older than ACI, mBMS, and MC patients ($p < 0.01$).

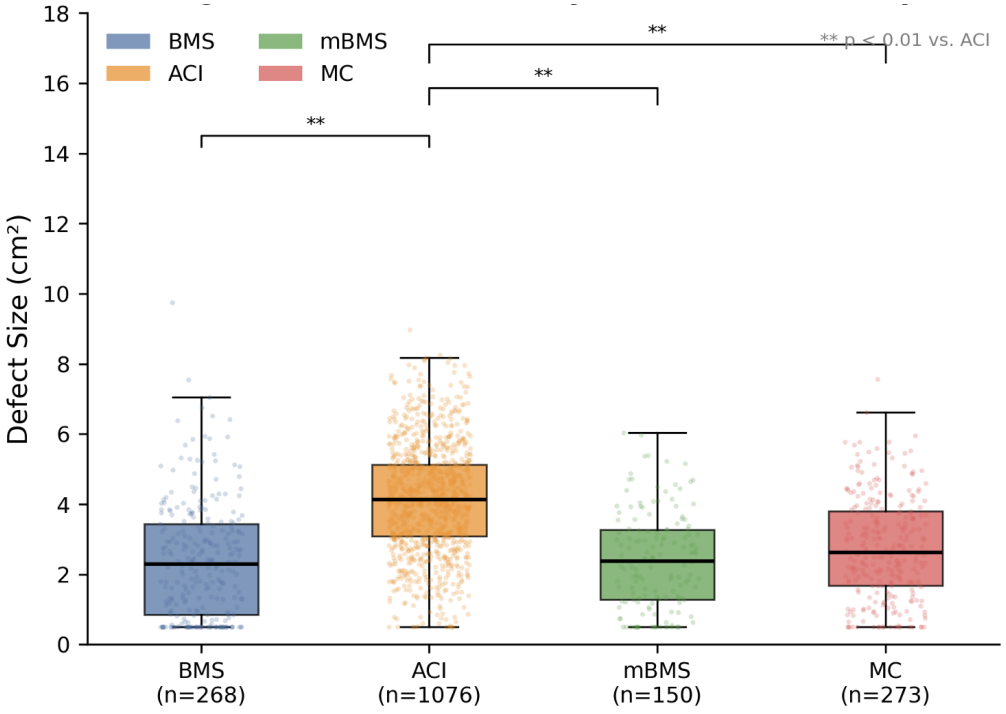

Figure 3. Defect size (cm^2) by treatment modality. Box-and-whisker plots with individual data points (jitter dots). ACI patients presented with significantly larger defect sizes compared to all other groups (all $p < 0.01$). ** $p < 0.01$. BMS, bone marrow stimulation; ACI, autologous chondrocyte implantation; mBMS, matrix-augmented bone marrow stimulation; MC, minced cartilage.

Table 2. Treatment Characteristics (Categorical Parameters) at Time of Surgery

Parameter	Category	BMS (%)	ACI (%)	mBMS (%)	MC (%)
Revision surgery	Yes	27.8	62.2	33.3	28.4
	No	72.2	37.8	66.7	71.6
Previous surgeries (affected defect)	0	89.5	44.4	74.3	84.8
	≥1	10.5	55.6	25.7	15.2
Previous surgeries (affected knee)	0	68.4	28.6	56.2	65.3
	≥1	31.6	71.4	43.8	34.7
ICRS grade	IIIa/IIIb	57.8	64.9	51.4	66.9
	IVa/IVb	38.0	34.6	48.0	32.7
Defect etiology	Traumatic	24.0	33.4	19.7	25.9
	Degenerative	61.6	31.6	55.8	63.2
	Post-traumatic	9.9	28.9	18.4	8.6
	Other (OCD)	4.6	6.1	6.1	2.3
KL grade	Normal	55.7	68.8	69.9	83.7
	I	27.8	25.9	19.5	10.3
	II–IV	16.5	5.2	10.6	5.9
Number of defects	1	81.7	81.8	83.0	84.2
	≥2	18.3	18.2	17.0	15.8

Data presented as frequency (%). Chi-squared test used for all comparisons. All differences in revision surgery and previous surgery proportions were statistically significant ($p < 0.01$). ICRS, International Cartilage Repair Society; KL, Kellgren-Lawrence; OCD, osteochondritis dissecans.

Table 3. Defect Localization by Treatment Modality ($p < 0.01$, chi-squared)

Location	BMS (%)	ACI (%)	mBMS (%)	MC (%)
Patella	11.6	46.6	33.6	33.8
Trochlea	15.0	16.2	22.8	30.5 †
MFC	48.3	22.7	24.8	19.9
LFC	15.0	13.8	10.7	14.3
MTP	6.4	0.2	3.4	0.7
LTP	3.7	0.6	4.7	0.7

† MC had the highest proportion of trochlear defects of all groups. MFC, medial femoral condyle; LFC, lateral femoral condyle; MTP, medial tibial plateau; LTP, lateral tibial plateau.

Concomitant Surgical Procedures

The frequency of concomitant surgical procedures was significantly lower in MC patients (44.7% with at least one concomitant procedure) compared to ACI (61.9%; $p < 0.01$) and BMS (61.6%; $p < 0.01$), but comparable to mBMS (55.3%; p = NS) (**Table 4, Figure 5**). ACI patients also showed a significantly higher rate of concomitant procedures compared to mBMS ($p = 0.023$).

When examining specific procedure types, partial meniscectomy was most frequent in BMS (36.6%) and substantially less common in ACI (3.3%). Patella stabilization (soft tissue and bony combined) was markedly more frequent in ACI (43.5%) and mBMS (24.0%) compared to MC (12.8%) and BMS (6.0%). Osteotomies were most frequent in ACI (15.8%) compared to MC (2.2%), which showed the lowest osteotomy rate of all groups. Ligament reconstruction rates were highest in ACI (7.7%) and lowest in MC (2.9%).

Discussion

Summary of Key Findings

The present cross-sectional registry analysis demonstrates that, within the German Cartilage Registry, MC has been predominantly applied for small-to-medium-sized articular cartilage defects of the knee (mean 2.52 cm^2), consistent with current DGOU expert recommendations and statistically comparable to BMS and mBMS in terms of defect size. The study hypothesis was confirmed: MC is used in a distinctly different indication spectrum than ACI, which is preferentially applied for larger defects in a more complex revision setting. Three additional findings warrant detailed discussion: (1) the disproportionately high frequency of trochlear defects in the MC group; (2) the significantly lower rate of concomitant surgical procedures in MC patients compared to ACI and BMS; and (3) the broadly comparable age profiles of MC, ACI, and mBMS patients, contrasting with the substantially older BMS cohort.

Defect Size and Indication Spectrum

The mean defect size of 2.52 cm^2 observed in this registry cohort closely corresponds to the 2.77 cm^2 reported by Frodl et al. in their meta-analysis of MC clinical studies, suggesting that the registry population is broadly representative of the published MC patient population. The defect size range of MC places it firmly within the BMS and mBMS indication spectrum rather than the ACI range. This is scientifically meaningful, as current evidence-based guidelines position ACI as the preferred option for medium-to-large defects (generally ≥2–3 cm^2) in younger active patients where long-term durability is paramount [1][11]. The systematic review by Angele et al. (2022) of Level-1 studies with ≥5-year follow-up confirmed that restorative procedures (ACI variants and OAT) yield superior long-term outcomes compared to reparative approaches (BMS) for larger defects [1]. The 10-year MACI prospective cohort by Ebert et al. (2024) demonstrated durable PROM improvements and 92% patient satisfaction at 10 years, further supporting the long-term value of ACI for appropriately selected patients [4]. By contrast, BMS durability deteriorates over time, as demonstrated by the 10-year randomized controlled trial by Volz et al. (2024) in which microfracture outcomes declined while AMIC remained stable [3].

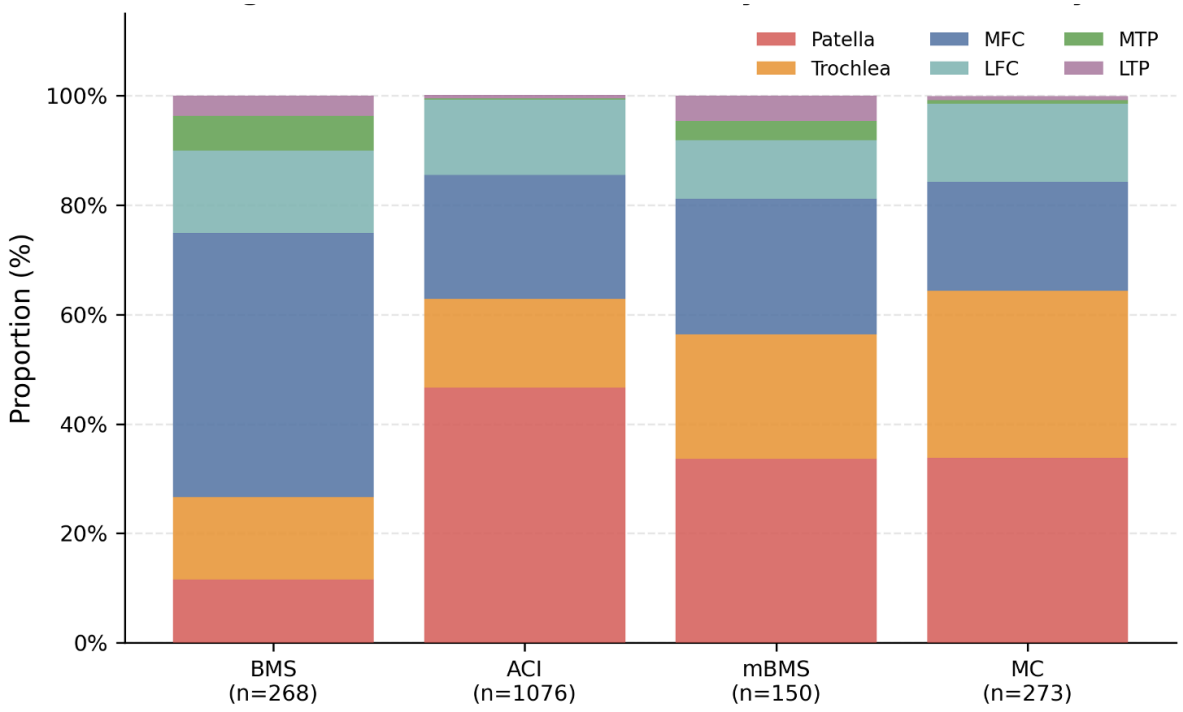

Figure 4. Defect localization by treatment modality. Stacked bar chart. The proportion of trochlear defects was highest in the MC group (30.5%; $p < 0.01$, chi-squared). MFC, medial femoral condyle; LFC, lateral femoral condyle; MTP, medial tibial plateau; LTP, lateral tibial plateau.

Table 4. Concomitant Surgical Procedures by Treatment Modality

Procedure	BMS (%)	ACI (%)	mBMS (%)	MC (%)
None	38.4	38.1	44.7	55.3 **
Valgization HTO	7.1	5.7	5.3	2.2
Valgization DFO	1.5	1.0	0.0	0.0
Varization DFO	0.7	6.6	2.7	0.0
Varization HTO	0.0	0.4	0.0	0.0
Rotational osteotomy	0.0	1.8	0.0	0.0
ACL reconstruction	6.3	7.1	4.7	2.9
PCL reconstruction	0.7	0.1	0.0	0.0
MCL/LCL reconstruction	0.7	0.5	0.0	0.0
Meniscus refixation	10.8	5.4	4.0	5.1
Partial meniscectomy	36.6 ‡	3.3 ‡	12.7	14.7
Meniscus allograft	0.0	0.4	0.0	0.0
Meniscus implant	0.0	0.1	0.0	0.0
Patella stabilization (soft)	4.9	34.9 §	20.7 §	9.9 §
Patella realignment (bony)	1.1	8.6	3.3	2.9

** Overall concomitant procedure rate significantly lower in MC vs. ACI and BMS ($p < 0.01$). ‡ Partial meniscectomy significantly lower in ACI vs. MC ($p < 0.001$); significantly higher in BMS vs. all others ($p < 0.001$). § Patella stabilization significantly more frequent with ACI, mBMS, and MC vs. BMS ($p < 0.001$ for ACI and mBMS; $p = 0.025$ for MC). HTO, high tibial osteotomy; DFO, distal femoral osteotomy; ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; MCL, medial collateral ligament; LCL, lateral collateral ligament.

Trochlear Defect Distribution

A particularly noteworthy finding is the disproportionately high proportion of trochlear defects in the MC group (30.5%), substantially exceeding the proportions in BMS (15.0%), ACI (16.2%), and mBMS (22.8%). This pattern likely reflects a specific treatment philosophy among surgeons using MC in the patellofemoral compartment. Trochlear defects present unique surgical challenges due to the complex three-dimensional geometry of the trochlear groove, the difficulty of achieving stable graft fixation in open approaches, and the frequent coexistence of patellofemoral malalignment. The one-stage arthroscopic nature of MC, combined with its technical simplicity and ability to conform to irregular defect shapes, may make it particularly attractive for trochlear lesions where conventional open ACI techniques are more demanding. This hypothesis is supported by Blanke et al. (2024), who included a substantial proportion of trochlear lesions (n = 20) in their MC cohort and reported favorable clinical and MRI outcomes [7]. However, the 10-year MACI cohort by Ebert et al. (2024) reported inferior patellofemoral compared to tibiofemoral outcomes at 10 years [4], suggesting that patellofemoral location may represent an inherently less favorable environment for cartilage regeneration regardless of technique. Whether the higher trochlear proportion in the MC group reflects a deliberate indication strategy, surgeon preference, or a systematic selection bias requires further investigation.

Concomitant Surgical Procedures and Clinical Implications

The significantly lower rate of concomitant surgical procedures in MC patients compared to ACI and BMS represents one of the most clinically important and critically interpretable findings of this study. Co-treatment of concomitant pathologies - including lower-limb malalignment, patellofemoral instability, ligamentous insufficiency, and meniscal pathology - is widely recognized as a cornerstone of successful cartilage regeneration surgery. The substantially higher osteotomy and patella stabilization rates in ACI patients (osteotomies: 15.8%; patella stabilization: 43.5%) compared to MC patients (osteotomies: 2.2%; patella stabilization: 12.8%) likely reflect both the higher

complexity of the ACI patient population and the more rigorous pre-operative workup associated with ACI, which — as a pharmaceutical product in Germany — is subject to stringent regulatory and reimbursement requirements mandating comprehensive pre-operative diagnostics and concomitant pathology management. The lower osteotomy and corrective surgery rates in MC patients do not appear to be explained by a genuinely lower prevalence of concomitant pathology, as defect etiology, ICRS grade, and joint surface integrity were broadly comparable across groups. This observation is viewed critically by the authors. The principles of comprehensive concomitant pathology management, refined over decades of ACI practice, should not be abandoned when applying newer, technically simpler procedures such as MC. The learnings from recent years regarding the importance of co-treatment must be stringently transferred to newly introduced techniques.

Surgeon-Related Bias and Treatment Philosophy

The possible influence of surgeon cohort composition deserves explicit acknowledgment. Surgeons performing MC within this registry may not be identical to those performing ACI, and differences in subspecialty training, institutional protocols, and familiarity with comprehensive cartilage surgery workup could contribute to the observed differences in concomitant procedure rates. This represents a form of surgeon-related bias that cannot be fully controlled in a registry analysis. Furthermore, the surgeons active in the KnorpelRegister DGOU are not representative of all orthopedic surgeons in Germany; they are characterized by an intrinsic interest in cartilage regeneration science, which may translate into more conservative and guideline-adherent MC utilization than in the broader orthopedic community.

Comparison with Published MC Outcome Data

The clinical outcome data now available for MC are encouraging but require careful interpretation. Runer et al. (2023) reported the first minimum 5-year follow-up data for MC, demonstrating sustained IKDC improvements and a low revision rate of 3.5% - an important milestone in establishing long-term durability [8]. Schneider et al. (2024) and Blanke et al. (2024) confirmed meaningful short-to-mid-term clinical improvements in larger prospective cohorts [6][7]. A matched-pair analysis comparing MC with ACI found comparable clinical outcomes in selected patients, supporting MC as a viable one-stage alternative for appropriately sized defects [9]. However, Behrendt et al. found superior outcomes for mBMS/AMIC compared to hand-minced cartilage at 2-4 years [10], highlighting that not all MC variants may perform equivalently. The heterogeneity of MC techniques - including differences in mincing method (hand versus shaver), fragment size, matrix augmentation (fibrin, PRP, collagen membrane), and surgical approach (arthroscopic versus mini-open versus open) - represents a major source of variability in the literature and a critical limitation for evidence synthesis.

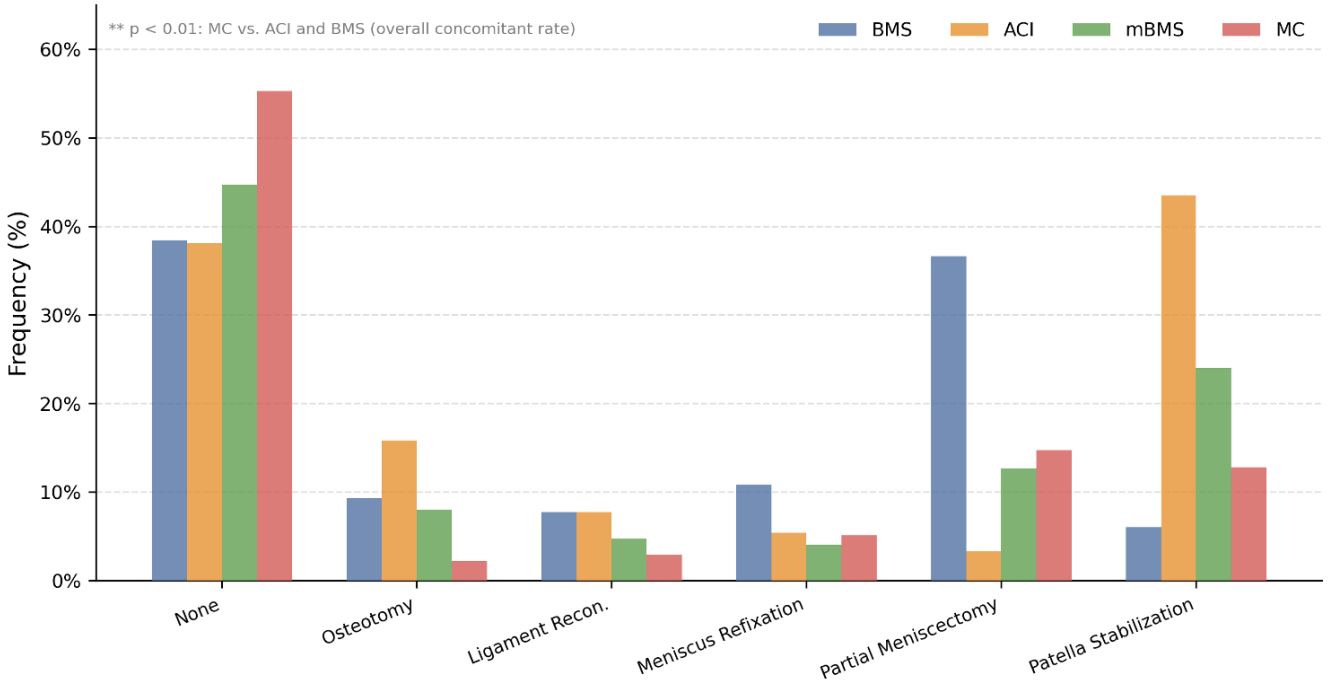

Figure 5. Concomitant surgical procedures by treatment modality. Grouped bar chart illustrating the frequency of specific concomitant procedures. The overall rate was significantly lower in MC compared to ACI and BMS ($p < 0.01$).

Strengths and Limitations

The primary strength of this analysis is the use of a large, prospectively maintained national registry with standardized data collection across 125 specialized cartilage surgery centers, providing real-world insights into treatment patterns that cannot be obtained from single-center studies or randomized trials. The contemporaneous comparison of four treatment modalities within an identical calendar period minimizes temporal confounding. Registry-based analyses of this type are increasingly recognized as essential complements to randomized controlled trials for understanding real-world clinical practice.

Important limitations must be acknowledged. First, the KnorpelRegister DGOU represents a selected cohort of centers with a specific interest in cartilage regeneration science, which may not reflect the practice of all orthopedic surgeons in Germany. Second, the cross-sectional design precludes causal inference, and the absence of follow-up outcome data for MC patients limits conclusions about clinical effectiveness. Third, the heterogeneity of MC techniques within the registry - including variability in mincing approach, matrix augmentation, and surgical access - could not be fully characterized. Fourth, the absence of comprehensive comorbidity stratification and surgeon-level data prevents adjustment for potential confounders. Fifth, the unequal group sizes may have affected statistical power for some pairwise comparisons. Sixth, the relatively short follow-up of MC patients within the registry means that medium-to-long-term outcome data are not yet available.

Conclusion

This cross-sectional registry analysis demonstrates that, within the German Cartilage Registry, MC has been predominantly applied for small-to-medium-sized articular cartilage defects of the knee, consistent with current DGOU expert recommendations. The indication spectrum of MC overlaps with BMS and mBMS rather than ACI, and a disproportionately high proportion of trochlear defects was treated with MC. The significantly lower rate of concomitant surgical procedures in MC patients compared to ACI and BMS is viewed critically and may reflect a less systematic approach to concomitant pathology management in the MC setting. The established principles of comprehensive cartilage regeneration surgery - including systematic treatment of underlying pathologies - should be applied rigorously to MC as to all other cartilage regeneration techniques. MC represents a promising and increasingly relevant one-stage cartilage regeneration strategy; however, long-term outcome data and prospective comparative studies are still necessary before broad standardization and expansion of indications can be recommended.

Open access statement

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Conflict of Interest

The authors declare that they have no conflicts of interest relevant to this work.

Ethical Approval

The German Arthroscopy Registry (DART) is conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of the University of Freiburg (approval No. 624/19) and the local ethics committees of the participating centres. Written informed consent was obtained from all participants prior to registry enrolment.

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