의학박사 학위논문

자가 골연골 이식술 후 평균 6년 양적 MRI 추적 관찰: 임상결과 및 관절 연골의 질적 형태학적 평가

Serial quantitative MRI following osteochondral autograft transfer surgery demonstrates stable cartilage properties despite partial morphologic degeneration: A mean 6-year follow-up study.

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Serial quantitative MRI following osteochondral autograft transfer surgery demonstrates stable cartilage properties despite partial morphologic degeneration: A mean 6-year follow-up study.

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이 논문을 의학박사 학위 논문으로 제출함

2024년 5월

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Abstract

Background: Osteochondral autograft transfer surgery (OATS) is preferred because of its ability to replace defective cartilage with hyaline cartilage. However, longitudinal changes in hyaline cartilage status after OATS and their correlation with clinical outcomes remain unclear.

Purpose/Hypothesis: We hypothesized that (1) cartilage quality and morphology as evaluated by quantitative magnetic resonance imaging (MRI) would remain stable over a midterm follow-up period, and (2) interval changes in clinical outcomes would correlate with changes in either qualitative or morphologic outcomes.

Study Design: Case series; level of evidence, 4.

Methods: Among patients who underwent OATS between 2002. and 2019, those who underwent serial follow-up MRI at both the short-(1–3 years postoperatively) and mid-term (3–10 years postoperatively) were retrospectively reviewed. Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) 2.0 knee score was performed for morphological assessment of the cartilage. Cartilage T2 relaxation time (CRT2) was measured to assess cartilage tissue biocomposition. Clinical outcomes were assessed using the Lysholm score, International Knee Documentation Committee (IKDC) score, Tegner score, and the visual analog scale (VAS) for pain. Correlation analysis was conducted between clinical and MRI outcomes.

Results: A total of 23 patients with a mean age of 30.2±11.1 years (range, 16–49 years) were enrolled in this study. The mean short-term follow-up period was 1.3±0.4 years, and the mean mid-term follow-up period was 6.0±2.3 years. Between the follow-up intervals, the MOCART score decreased from 84.0±10.2 to 72.3±23.6 (P=.003). The CRT2 of the deep layer remained stable (P=.507), while the superficial layer improved from 50.6±5.6 to 48.0±5.0 (P=.019). Significant improvements were observed in the Lysholm, IKDC, and VAS scores that remained stable during the follow-up period.

However, neither a decreased MOCART score nor an improved CRT2 value affected the changes in clinical outcomes.

Conclusion: The tissue properties of the entire cartilage layer remained stable until the mid-term follow-up following OATS. Despite partial morphological degeneration, the MOCART score at mid-term follow-up still indicated a good cartilage status, and this degeneration did not lead to deterioration in clinical outcomes.

Key terms: Cartilage T2 relaxation time; mosaicplasty, osteochondral autograft transfer surgery, quantitative magnetic resonance imaging.

Contents

Introduction

Full-thickness cartilage defects in the knee joint can result from various conditions, including acute injury, juvenile osteochondritis dissecans, and chronic degeneration in the early stages of knee osteoarthritis.[1-3] If left untreated, localized cartilage defects can cause persistent pain, progressive chondral wear, and restricted daily activity, highlighting the importance of treating early localized chondral defects.[3-6] However, given the limited healing potential of native cartilage tissue, cartilage repair procedures are essential and have been increasingly utilized to enhance clinical outcomes.

Among the available options, osteochondral autograft transfer surgery (OATS) has been reported to achieve robust long-term clinical outcomes.[7, 8] Unlike other procedures, OATS offers the advantage of being a one-stage operation, with the repaired cartilage being hyaline rather than fibrous cartilage tissue. This distinction may be biologically beneficial in terms of cartilage tissue properties and durability, potentially enhancing clinical results and longevity. However, the role of hyaline cartilage, the longitudinal changes after transplantation, and their relationship with clinical outcomes have yet to be fully elucidated.[9, 10] Although many previous studies have utilized the Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) 2.0 knee score for the assessment of OATS outcome,[11] the assessment is limited because it only includes the assessment of morphologic findings from conventional magnetic resonance imaging (MRI).

Quantitative T2-mapping is increasingly utilized for the biochemical analysis of cartilage as a valid, noninvasive, and objective biomarker.[12-14] It is well established that Cartilage T2 relaxation time (CRT2) reflects the biocomposition of collagen and water content as well as disruptions in collagen structure.[15, 16] Therefore, increased intra-cartilaginous water content is correlated with increased CRT2, making it a clinically practical index of early degeneration in articular cartilage.[17-19] Nevertheless, no study has reported changes in cartilage status following OATS by using a quantitative method.

This study aimed to evaluate longitudinal changes in the morphology and quality of cartilage tissue following OATS, along with clinical outcomes over a midterm follow-up period. We hypothesized that (1) cartilage quality and morphology as evaluated by MOCART scores and CRT2 values would remain stable over a midterm follow-up period, and (2) the interval changes in clinical outcomes would correlate with changes in either MOCART scores or CRT2 values.

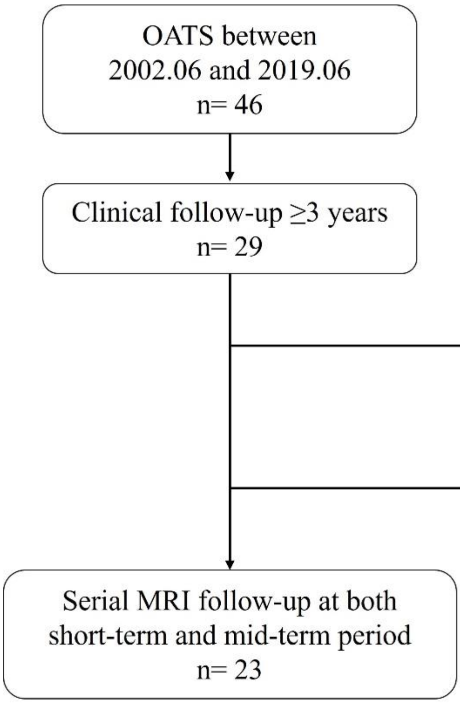
Materials and Methods

This retrospective study was approved by the Institutional Review Board of the medical center conducting the current study. The patient data were collected and assessed anonymously by the first author.

Patients

Between June 2002 and June 2019, a total of 46 patients underwent osteochondral autograft transfer surgery (OATS) at the Seoul Asan Medical Center. OATS was considered for patients with symptomatic focal cartilage defects whose characteristics corresponded to the International Cartilage Repair Society (ICRS) grade 3 or 4 lesions, measuring ≥ 1.0 cm^2. Conversely, OATS was not considered for patients with morbid obesity (body mass index [BMI] > 40), advanced osteoarthritis, a history of inflammatory arthritis, or autoimmune conditions. For patients with accompanying structural problems, the following concomitant procedures were considered: realignment osteotomy for patients with a mechanical axis deviation greater than 6°, meniscal allograft transplantation for patients exhibiting subtotal-to-total meniscectomy state of the knee; and anterior cruciate ligament (ACL) reconstruction for knees with ACL deficiency. Among patients who underwent OATS, those who underwent serial MRI at both short-term (1–3 years after surgery) and mid-term (3–10 years after surgery) follow-ups were enrolled in this study. Finally, a total of 23 patients who were assessed with serial MRI until the midterm follow-up period were enrolled in this study. (Figure 1)

Figure 1. Flowchart of patient enrollment.

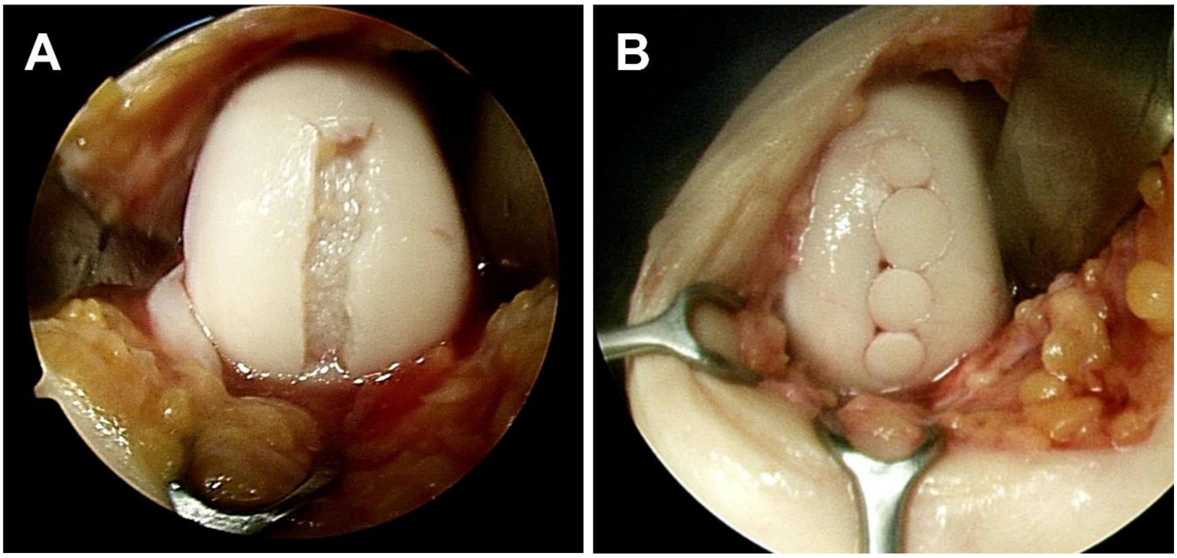


MRI, magnetic resonance imaging; OATS, osteochondral autograft transfer surgery; POD, postoperative day.

Surgical technique and postoperative management

Two senior surgeons (Seong-Il Bin and Jong-Min Kim) performed the OATS procedure, and both used the same surgical technique. The size and depth of the cartilage defect were measured via preoperative MRI, and the cartilage status of the non-weight-bearing area of the trochlea was assessed as a potential donor site. Once OATS was confirmed to be an appropriate treatment for a patient, an arthroscopic examination was conducted to evaluate the condition of the meniscus, cartilage, and ligaments. The cartilage status at the donor site was assessed and the area of the cartilage defect was intraoperatively measured using an arthroscopic probe. Subsequently, an arthrotomy was performed with a 5-cm skin incision to visualize the surface of the chondral defect. Using the OATS system (Arthrex, Naples, FL, USA), a recipient hole was created perpendicular to the surface. The minimum depth of the hole was set to 1.5 times the diameter of the hole to ensure a sufficient press-fit contact area between the healthy cancellous bone and the osteochondral plug. A perpendicular osteochondral plug was harvested from the donor site under direct visualization. Two cylindrical plugs from the recipient and donor sites were compared to adjust their lengths, and the healthy plug was trimmed to be slightly shorter than the damaged plug to prevent protrusion at the recipient site. If the damaged chondral lesion was not adequately covered by the healthy transferred plug, mosaicplasty was performed by harvesting multiple additional osteochondral plugs. Following this procedure, the capsule was repaired meticulously, ensuring that the cartilage surface of the recipient site was congruent. (Figure 2)

Figure 2. Intraoperative findings of a 49-year-old female who underwent osteochondral autograft transfer surgery.



The medial femoral condyle of the left knee was visualized via arthrotomy. (A) A longitudinally shaped full-thickness cartilage defect was observed on the weight-bearing portion of the medial femoral condyle. (B) Four healthy osteochondral plugs were transferred to the defective region, with congruency supervised under direct visualization.

Rehabilitation

Postoperatively, patients were advised to immediately initiate appropriate exercises such as quadriceps sets, and straight leg raises to accelerate the recovery of a full range of motion. The duration of non-weightbearing after OATS depended on the number and geometry of transplanted plugs. For one or two plugs, patients were advised to avoid weightbearing for two weeks, followed by partial weight bearing. Full weight bearing was permitted after four weeks postoperatively. In cases involving three or more plugs, where there was potential reduction in contact surface with neighboring host bone, a four-week period of non-weightbearing was recommended. This was followed by four weeks of partial weight bearing before allowing full weight bearing after eight weeks postoperatively. As a precaution, patients were advised to limit their physical activities to light sports such as cycling and swimming. Strenuous exercise and heavy labor were discouraged indefinitely to avoid potential complications related to the healing of the transplanted meniscus.

Quantitative 3-T MRI protocol

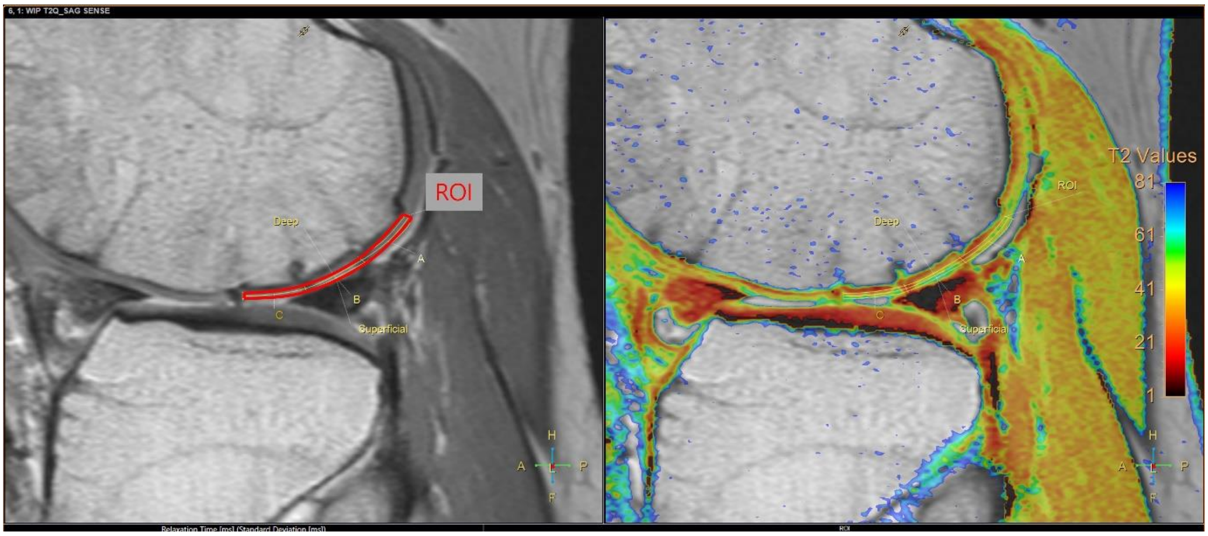
For postoperative monitoring, patients were recommended to undergo MRI after 1 year for short-term follow-up and every 2-3 years thereafter for regular follow-up. Postoperative cartilage status was assessed using MRI (Achieva 3T; Philips Healthcare, The Netherlands) with a dedicated 16-channel knee coil. MRIs conducted between 1-3 years postoperatively were categorized as short-term follow-up MRIs, whereas those conducted between 3-10 years postoperatively were denoted as mid-term follow-up MRIs. Longitudinal changes were then compared.

A quantitative T2 sequence was obtained in addition to conventional MRI. Quantitative MRI was performed using the following parameters: six echo times at 13, 26, 39, 52, 65, and 78 ms; a repetition time of 3,500 ms; slice thickness of 3 mm; field of view of, 160 × 160 mm; pixel matrix of, 304 × 304 mm; and a total acquisition time of, 7.93 min. The T2 relaxation times (measured in ms) were acquired using multi-echo measurements.

Qualitative assessment

Color T2 mapping images ranging from 1 to 81 ms were generated using an advanced cartilage assessment application (IntelliSpace Portal; Philips Healthcare, Netherlands). Region of interest (ROI) analysis was conducted on the cartilage of each osteochondral plug. The software automatically computed the mean T2 value of the cartilage for each osteochondral plug. Additionally, the ROIs were automatically divided into deep and superficial layers of equal thickness to evaluate the variation in T2 values across the different depths of the cartilage layer (Figure 3).[13, 15]

Figure 3. Quantitative T2 mapping for cartilage assessment after osteochondral autograft transfer surgery.



ROI segmentation for each osteochondral plug was performed and each segment was divided into two layers (superficial and deep). ROI, Region of interest

Morphological assessment

A MOCART 2.0 knee score was used as it enables the assessment of cartilage repair tissue after different cartilage repair techniques with good intra- and inter-rater reliability.[11] It comprises seven variables contributing to a total score of 100 that include: volume of the cartilage defect filling (0-20 points), integration into adjacent cartilage (0-15 points), surface of the repair tissue (0-10 points), structure of the repair tissue (0-10 points), signal intensity of the repair tissue (0-10 points), bony defects or bony overgrowth (0-10 points), and subchondral changes (0-20 points). (Table 1)

Table 1. MOCART 2.0 Knee score for cartilage repair tissue assessment: Grading and point scale.[11]

			Scoring
1	**Volume fill of cartilage defect**		
	1	Complete filling OR minor hypertrophy: 100% to 150% filling of total defect volume	20
	2	Major hypertrophy ≥150% OR 75% to 99% filling of total defect volume	15
	3	50% to 74% filling of total defect volume	10
	4	25% to 49% filling of total defect volume	5
	5	<25% filling of total defect volume OR complete delamination in situ	0
2	**Integration into adjacent cartilage**		
	1	Complete integration	15
	2	Split-like defect at repair tissue and native cartilage interface ≤2 mm	10
	3	Defect at repair tissue and native cartilage interface >2 mm, but <0% of repair tissue length	5
	4	Defect at repair tissue and native cartilage interface ≥50% of repair tissue length	0
3	**Surface of the repair tissue**		
	1	Surface intact	10
	2	Surface irregular <50% of repair tissue diameter	5
	3	Surface irregular ≥50% of repair tissue diameter	0
4	**Structure of the repair tissue**		
	1	Homogeneous	10
	2	Inhomogeneous	0
5	**Signal intensity of the repair tissue**		
	1	Normal	15
	2	Minor abnormal—minor hyperintense OR minor hypointense	10
	3	Severely abnormal—almost fluid like OR close to subchondral plate signal	0
	4	Subchondral cyst ≥5 mm in longest diameter OR osteonecrosis-like signal	0

(continued)

Table 1. (continued)

			Scoring
6	**Bony defect or bony overgrowth**		
	1	No bony defect or bony overgrowth	10
	2	Bony defect: depth < thickness of adjacent cartilage OR overgrowth <50% of adjacent cartilage	5
	3	Bony defect: depth ≥ thickness of adjacent cartilage OR overgrowth ≥50% of adjacent cartilage	0
7	**Subchondral changes**		
	1	No major subchondral changes	20
	2	Minor edema-like marrow signal—maximum diameter <50% of repair tissue diameter	15
	3	Severe edema-like marrow signal—maximum diameter ≥50% of repair tissue diameter	10
	4	Subchondral cyst ≥5 mm in longest diameter OR osteonecrosis-like signal	0

MOCART = Magnetic Resonance Observation of Cartilage Repair Tissue.

Intra-reader reproducibility

Intraclass correlation coefficients were calculated for the MOCART scores. Ten patients were randomly reviewed by Hyo Yeol Lee and another orthopedic surgeon who were not involved in this study 1 month after the initial assessment to investigate the validity of the measurement method. The coefficient of repeatability was evaluated using the intraclass correlation coefficient. The strength of agreement was interpreted as follows: ≥ 0.91, almost-perfect agreement; 0.71 to 0.90, good agreement; 0.61 to 0.70, acceptable agreement; and below 0.60, unacceptable agreement. In the present study, the intra-observer reliability and inter-observer agreement were 0.908 (95% confidence interval 0.629-0.977; P =.001) and 0.894 (95% confidence interval 0.573-0.974; P=.001), respectively. These results were interpreted to be in good agreement.

Clinical outcome assessment

Clinical outcomes were assessed using the Lysholm score, International Knee Documentation Committee (IKDC) subjective knee score, Tegner Activity Scale, and Visual Analog Scale (VAS) for pain preoperatively and during follow-up visits. Moreover, minimal clinically important difference (MCID) and patient acceptable symptom state (PASS) analyses were used to assess clinical relevance and significance. The percentage of patients who showed improvements exceeding the MCID and PASS scores at the final follow-up was calculated.

Statistical analysis

SPSS statistical software (version 25.0; IBM) was used for statistical analyses. Statistical significance was set at $P < .05$. The Wilcoxon signed rank test was used to verify longitudinal changes in clinical and MRI outcomes. The Spearman rank coefficient correlation test was conducted to assess the correlation between CRT2 and MOCART scores, and the relationship between clinical outcomes and MRI findings.

Result

Patient Characteristics

The mean short-term follow-up period was 1.3±0.4 years (range, 0.9–2.0 years) and the mean mid-term follow-up period was 6.0±2.3 years (range, 3.5–9.9 years) (Figure 3). This study included 15 men and 8 women with a mean age of 30.2±11.1 years (range, 16–49 years). The mean defect area was 2.5±1.3 (1.0–6.3) cm^2 and the mean number of osteochondral plugs used was 2.3±1.5 per case. The etiologies of the lesions were focal high-grade chondral defect (17 knees), juvenile osteochondritis dissecans (five knees), and osteochondral fracture (one knee). Twelve patients (52%) underwent concomitant procedures during OATS. Patient characteristics are summarized in Table 2.

Table 2. Patient characteristics

	Total (n=23)
Age, y	30.2±11.1 (16–49)
Sex (Male:Female), n	15:8
Side (Right:Left), n	13:10
Location (Medial:Lateral), n	9:14
BMI	25.5±4.2 (20.2–35.4)
Short-term follow-up period, y	1.3±0.4 (0.9–2.0)
Mid-term follow-up period, y	6.0±2.3 (3.5–9.9)
Axis (varus), °	0.6±3.1 (-5.3–6.0)
Plug number, n	2.3±1.5 (1–7)
Plug diameter, mm	9.2±1.4 (6.0–10.0)
Plug depth, mm	15.0±1.3 (13.0–18.0)
Defect area, cm^2	2.5±1.3 (1.0–6.3)
Etiology of cartilage defect	
Focal cartilage defect	17
Juvenile osteochondral dissecans	5
Osteochondral fracture	1
Concomitant procedure	
Isolated OATS	11
Combined lateral MAT	11
Combined ACL recon.	1

BMI, body mass index; OATS, osteochondral autograft transfer surgery; MAT, meniscal allograft transplantation; ACL, anterior cruciate ligament.

Qualitative and morphologic changes in cartilage tissue

Morphological and qualitative changes in cartilage tissue between the follow-ups are summarized in Table 3. The mean total MOCART score significantly declined from 84.0±10.2 at initial follow-up to 72.3±23.6 at mid-term follow-up (P=.006). Of the seven variables determining the MOCART score, the "Volume of cartilage defect filling" and the "Structure of the repair tissue" were primarily responsible for the observed decline in the score from 17.0±3.5 to 14.1±7.5 (P=.019) and from 8.3±3.8 to 5.7±5.0 (P=.014), respectively.

Table 3. Morphologic and qualitative changes in cartilage during serial follow-up.

	Short-term follow-up	Mid-term follow-up	P-value
Follow-up period, y	1.3±0.4 (0.9–2.0)	6.0±2.3 (3.5–9.9)	**<.001**
MOCART 2.0 score (total)	84.0±10.2	72.3±23.6	**.006**
1. Volume of Cartilage Defect filling	17.0±3.5	14.1±7.5	**.019**
2. Integration into adjacent cartilage	14.3±1.7	13.3±3.2	.160
3. Surface or the Repair Tissue	5.2±3.5	5.2±3.8	1.000
4. Structure of the Repair Tissue	8.3±3.8	5.7±5.0	**.014**
5. Signal intensity of the Repair Tissue	13.7±2.2	13.0±2.4	.257
6. Bony Defect or Bony Overgrowth	8.3±2.8	7.6±3.6	.366
7. Subchondral Changes	17.0±4.4	16.7±4.6	.705
Quantitative MRI T2 mapping			
CRT2 of entire layer	47.0±5.8	46.0±4.5	.159
CRT2 of deep layer	43.7±7.2	43.4±5.7	.507
CRT2 of superficial layer	50.6±5.6	48.0±5.0	**.019**

The Wilcoxon signed-rank test was also performed. The bold interface indicates statistical significance. (P value <.05). CRT2, Cartilage T2 relaxation time; MRI, magnetic resonance imaging; MOCART, Magnetic Resonance Observation of Cartilage Repair Tissue.

Conversely, CRT2 values of the entire cartilage layer remained stable during the midterm follow-up period. Further zonal analysis revealed that while the deep layer of the cartilage tissue remained stable, the superficial layer exhibited a small but significant improvement, from 50.6±5.6 to 48.0±5.0 (P=.019). Correlation analysis revealed no significant association between the changes in CRT2 values and the total MOCART scores. However, upon examining variables that determine the MOCART score, a moderate positive linear correlation (rho=.459) with a statistical significance (p=0.048) was revealed between “Structure of the Repair Tissue” that represents the changes in tissue homogeneity and the CRT2 value of the entire layer. (Table 4)

Table 4. Correlation between changes in cartilage T2 relaxation time and MOCART score.

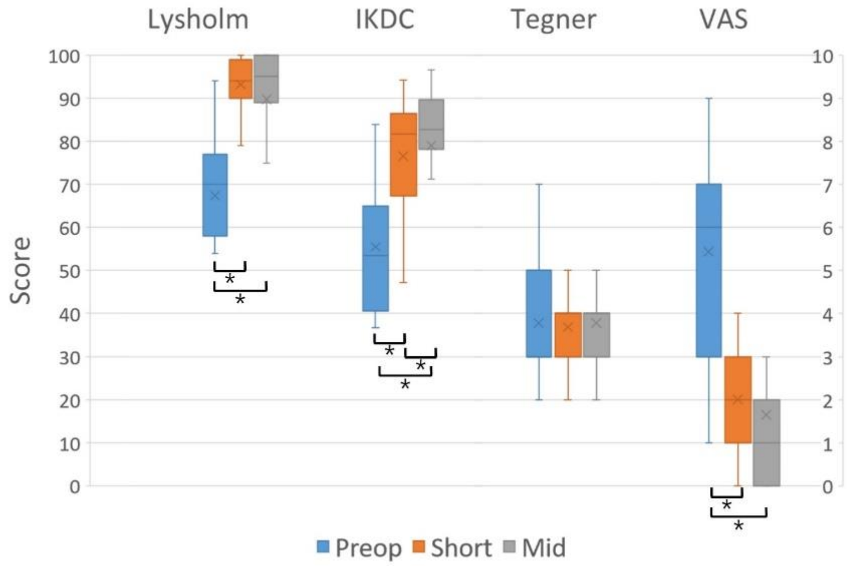
	ΔCRT2					
	entire layer		deep layer		superficial layer	
	rho	P-value	rho	P-value	rho	P-value
ΔMOCART	0.062	0.800	-0.153	0.531	0.056	0.820
ΔMOCART1	-0.083	0.737	-0.258	0.287	-0.030	0.904
ΔMOCART2	-0.120	0.625	-0.453	0.052	0.127	0.603
ΔMOCART3	-0.282	0.241	-0.256	0.289	-0.376	0.112
ΔMOCART4	**.459***	**0.048**	0.393	0.096	0.360	0.130
ΔMOCART5	-0.133	0.586	-0.133	0.586	-0.106	0.666
ΔMOCART6	0.196	0.420	0.283	0.240	0.044	0.858
ΔMOCART7	0.143	0.559	-0.041	0.868	0.260	0.283

Spearman correlation coefficient analysis revealed no significant association between changes in CRT2 and the total MOCART score. However, upon examining variables accounts for the MOCART score, a moderate positive linear correlation (rho=.459) with a statistical significance (p=0.048) was found between “Structure of the Repair Tissue” that represents the changes in tissue homogeneity and CRT2 of the entire layer. Bold interface indicates statistical significance. CRT2, Cartilage T2 relaxation time; MOCART, Magnetic Resonance Observation of Cartilage Repair Tissue. MOCART1. Volume fill of cartilage defect; MOCART2, Integration into adjacent cartilage; MOCART3, Surface of the repair tissue; MOCART4, Structure of the repair tissue; MOCART5, Signal intensity of the repair tissue; MOCART6, Bony defect or bony overgrowth; MOCART7, Subchondral changes.

Clinical outcomes

Figure 4 shows longitudinal changes in clinical outcomes during the midterm follow-up period. Lysholm score values showed a significant increase from 66.7±17.9 preoperatively to 93.2±6.5 at postoperative short-term follow-up ($P<.001$) and remained stably elevated to 89.1±19.3 ($P=.615$) at postoperative mid-term follow-up. IKDC scores showed a significant increase from 55.9±15.1 preoperatively to 76.5±12.5 at postoperative short-term follow-up ($P=.006$) and showed further improvement to 78.7±21.1 ($P=.013$) at postoperative mid-term follow-up. The mean VAS for pain demonstrated a significant improvement from 5.6±2.3 preoperatively to 2.0±2.1 at the postoperative short-term follow-up ($P\leq.001$) and remained stably reduced at 1.8±2.4 ($P=.126$) at the postoperative mid-term follow-up. The mean Tegner activity scale scores did not change significantly throughout the follow-up period.

Figure 4. Longitudinal change in clinical outcomes after osteochondral autograft transfer surgery.



Wilcoxon signed rank test was performed. Lysholm score and VAS for pain improved during short-term follow-up (postoperative 1–2 years) and remained stable until mid-term follow-up (postoperative 3-9 years). The IKDC score showed consistent improvement during the serial follow-up. The Tegner activity scale did not show significant improvement. The blue box indicates preoperative score; the orange box indicates short-term follow-up; the gray box indicates mid-term follow-up. IKDC, International Knee Documentation Committee; VAS, Visual Analog Scale for pain. * indicates stastically significant change.

Among the patient-reported outcome measures following OATS, the Lysholm and IKDC scores documented the MCID and PASS values. The published MCID values for the Lysholm and IKDC subjective knee scores are 10.1 and 16.7, respectively, while the PASS values for the Lysholm and IKDC scores have been reported as 70.0 and 62.1, respectively. Of these patients, 90.5% (Lysholm score) and 75.0% (IKDC score) achieved MCID values. Moreover, 95.7% (Lysholm score) and 91.3% (IKDC score) of patients surpassed the PASS values.

The results of the correlation analysis between MRI findings (including MOCART score and CRT2 values) and clinical outcomes showed that neither a reduced MOCART score nor an improved CRT2 value affected clinical outcomes. (Table 5)

Table 5. Correlation between changes in clinical outcome and MRI findings.

	ΔLysholm		ΔIKDC		ΔTegner		ΔVAS	
	rho	P-value	rho	P-value	rho	P-value	rho	P-value
ΔMOCART	-.118	.631	-.113	.587	-.243	.332	.043	.861
ΔCRT2								
entire layer	.430	.085	.074	.777	.355	.162	.098	.707
deep layer	.354	.164	.227	.382	.209	.421	.109	.678
superficial layer	.368	.146	.023	.931	.355	.162	-.033	.899

Spearman correlation coefficient was conducted. A higher rho value indicates stronger linear correlation. A P value <.05 was regarded as statistically significant. The results of correlation analysis between MRI findings (including MOCART score and CRT2 values) and clinical outcomes revealed that neither decreased MOCART score nor improved CRT2 affected the change in clinical outcomes. CRT2, Cartilage T2 relaxation time; IKDC, International Knee Documentation Committee; MOCART, Magnetic Resonance Observation of Cartilage Repair Tissue; MRI, magnetic resonance imaging; VAS, visual analog scale for pain.

Discussion

In this study, OATS resulted in excellent clinical and morphological outcomes during the midterm follow-up period. Although the serial follow-up MRI results showed morphologic degeneration between the follow-up intervals, the mean MOCART score at mid-term follow-up was 72.3±23.6 that is indicative of a good cartilage status. More importantly, we noted that the clinical outcomes and cartilage properties, as assessed by CRT2, remained stable or even showed partial improvement in the superficial layer at a mean of 6 years. This finding suggests that the transferred hyaline cartilage in OATS is durable enough to support a positive clinical outcome despite partial cartilage degeneration up to the mid-term follow-up period.

The most notable advantage of OATS is its ability to replace cartilage defects with hyaline cartilage rather than fibrous tissue regeneration.[20] Previous studies have demonstrated that OATS offers superior clinical outcomes and longer-term survival than microfracture, suggesting that these benefits may have resulted from the differences between hyaline and fibrous cartilage.[7, 21] However, the mechanisms underlying the changes within the transplanted hyaline cartilage remain unclear. The present study utilized quantitative T2 mapping, a robust and non-invasive technique for cartilage assessment, to investigate changes following OATS.[15, 16] The CRT2 values of the entire cartilage layer remained stable over serial follow-up periods postoperatively. Additionally, zonal analysis, depending on depth variation, indicated a small but statistically significant decrease in the CRT2 values of the superficial layer. Given that lower CRT2 values are typically observed in healthy knees, with increases in CRT2 associated with cartilage degeneration,[17, 22, 23] this decrease suggests an improvement in the cartilage properties of the superficial layers. However, caution is required when interpreting these results, and to our knowledge, this study is the first to document longitudinal changes in CRT2 following OATS. A comprehensive understanding of CRT2 dynamics is essential, given that they are influenced by a variety of conditions.[24-26]

Another advantage of OATS over other surgeries is that it replaces the osteochondral defect lesions with healthy subchondral bone. Previous studies have emphasized the underlying subchondral bone condition that affects the outcome of cartilage repair procedures. Gersing et al. found that subchondral trabecular bone parameters have significant correlations with CRT2 after matrix-associated autologous chondrocyte implantation.[27] Similarly, Mukai et al. reported that bone marrow edema observed via MRI was well correlated with plug union and necrosis after OATS.[28] In this study, we observed no complications associated with the osteochondral plug, such as necrosis or progression of bone marrow edema. Assessment of the subchondral structure using the MOCART 2.0 sub-score revealed no significant changes across follow-up intervals, potentially contributing to the favorable clinical outcomes observed at mid-term follow-up.

Despite the aforementioned findings, this study demonstrated no significant correlation between the changes observed via MRI and clinical outcomes. While there was a statistically significant improvement in the CRT2 value of the superficial layer, the amount of change was minimal. Similarly, in some cases, a partial reduction in cartilage thickness and increased tissue heterogeneity contributed to a notable decline in the mean total MOCART score. Nonetheless, the final mean MOCART score of 72.3 indicates a satisfactory cartilage repair status,[11, 29, 30] suggesting that these minor changes may not have a meaningful impact on patient-reported outcomes. Previous studies have also reported this mismatch, indicating that MRI findings after cartilage repair procedures, such as matrix-associated autologous chondrocyte implantation[27] or OATS[28] do not necessarily correlate with clinical outcomes. However, the minor but progressive morphological deterioration observed in the present study underscores the importance of managing contributing factors such as age, lesion size, lower limb alignment, BMI, residual meniscal volume, and concomitant procedures that could enhance long-term surgical outcomes.[4, 31, 32]

This study has strength as it adds information on longitudinal changes in cartilage tissue quality through quantitative MRI assessment. Compared to previous studies that focused on clinical and structural outcomes following OATS at specific time points using conventional MRI,[7, 8, 31, 33] this study enriches the comprehensive understanding of OATS and the role of hyaline cartilage for future research.

However, this study has several limitations. First, the small sample size may restrict the generalization of our findings. Second, this was a retrospective study design that did not include a control group. A comparison with other cartilage repair techniques, such as microfracture that primarily result in the formation of fibrocartilage rather than hyaline cartilage, would have enriched the insights into the influence of hyaline cartilage on surgical outcomes. Third, only 23 out of 46 patients were assessed with serial MRI and enrolled in this study, which could result in selection bias. Finally, the absence of histological analysis prevented a more detailed assessment of hyaline cartilage repair at the cellular level.

Conclusion

The tissue properties of the entire cartilage layer remained stable until the mid-term follow-up following OATS. Despite partial morphological degeneration, the MOCART score at mid-term follow-up still indicated a good cartilage status, and this degeneration did not lead to deterioration in clinical outcomes.

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