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Evaluation of radiographic knee OA progression after arthroscopic meniscectomy compared with IACI for degenerative meniscus tear

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The intra-articular corticosteroid injection (IACI) and arthroscopic partial meniscectomy (APM) are crucial treatment options for meniscus tears and are widely used in clinical practice. To determine whether there are differences in the progression of osteoarthritis (OA) after APM and IACI treatments for degenerative meniscal tears, and to identify the influencing factors. We finally collected the minimum joint space width (JSW), WOMAC score, and KOOS score of 189 patients after 4 years of follow-up. The mixed effects model and general estimating equation were used to analyze the differences in the progression of knee osteoarthritis and the factors affecting the progression of knee osteoarthritis in patients with degenerative meniscus tears who received different treatments. Over a 48-month follow-up period, all three groups showed a decreasing trend in knee JSW, with the IACI group having the fastest JSW decline rate at -0.020 mm/month (95% CI: -0.027 to -0.013, $p < 0.01$). There was no statistically significant difference in the JSW decline rate among the three groups. The WOMAC total scores for both the IACI and APM groups showed an improving trend, at -0.123/month (95% CI: -0.211 to -0.036, $p < 0.01$) and − 0.115/month (95% CI: -0.201 to -0.028, $p < 0.01$) respectively, with no statistical difference between the two groups. BMI was also a significant factor affecting postoperative JSW (regression coefficients: -0.012, 95% CI: -0.022 to 0.001, $p = 0.03$) and WOMAC total scores (regression coefficients: 0.189, 95% CI: 0.008 to 0.370, $p = 0.04$). Compared to single IACI, multiple IACI treatments resulted in faster JSW decline (B: 0.430, 95% CI: 1.012 to 2.336, $p = 0.04$). Patients with degenerative meniscal tears who undergo either IACI or APM treatment exhibit more pronounced progression of knee osteoarthritis compared to those in the non-treatment group. This form of deterioration is mainly driven by BMI.

Keywords Degenerative meniscus tear, Intra-articular corticosteroid injection, Arthroscopic partial meniscectomy, Knee osteoarthritis

Meniscal tears are a common sports-related injury, with approximately 66 cases per 100,000 individuals, accounting for 12-14% of orthopedic treatments[1–4]. Degenerative meniscus tears are common in middle-aged and elderly people, leading to knee pain, swelling, and limited mobility[1,5–11]. Due to the limited blood supply to the meniscus, the majority of meniscal tears do not heal spontaneously[12]. Plus, meniscal tears can result in knee joint instability and increased stress on the articular cartilage, leading to increased cartilage damage, narrowing of the joint space, and progression of osteoarthritis[1,4].

Treatment options for meniscal tears typically include conservative management (physical therapy, oral nonsteroidal anti-inflammatory drugs, etc.) and invasive treatments (IACI and surgical interventions)[10,11,13–15]. IACI have been used as a longstanding treatment method for knee joint pain, effectively alleviating local signs and symptoms in patients with meniscal injuries[16–18]. Studies by Bucci and Latourte et al. have shown that, compared to hyaluronic acid, IACI do not accelerate the progression of knee osteoarthritis (OA)[19,20]. However, the safety of IACI therapy remains questionable, as it may accelerate the progression of knee joint osteoarthritis[16,21]. Current research reports have found that corticosteroids have a detrimental effect on cartilage[22,23]. Furthermore, other studies have reported that IACI reduces meniscal volume and promote the progression of knee OA[16,23,24].

Arthroscopic partial meniscectomy (APM) is currently one of the most common orthopedic surgeries and the accepted surgical treatment for meniscal tears[1,25–28]. It offers advantages such as minimally invasive

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procedures, faster patient recovery and fewer postoperative complications[29–31]. Several randomized controlled trials have shown that, although APM does not result in better clinical outcomes compared to non-surgical treatment, nearly 30% of patients with mild to moderate OA and meniscal tears who initially received non-surgical treatment eventually opted for APM due to unresolved symptoms[13,32]. Therefore, APM remains an important treatment option for clinicians managing meniscal tears and mild to moderate OA[25,32]. APM can relieve patients' knee pain symptoms in a short period of time, but studies have shown that knees that have undergone APM exhibit significant structural changes on MRI compared to those that have not undergone APM[25,33,34]. A randomized controlled trial comparing APM with sham surgery demonstrated that knee joint osteoarthritis progressed faster in the APM group during a five-year follow-up period[33]. And another study found that patients who underwent APM had a faster decline in JSW compared to untreated meniscal tear patients and those without meniscal tears[25]. Vermesan et al. conducted a study on the prognostic outcomes of degenerative medial meniscal tears at one month and one year, and found that arthroscopic surgery showed slightly better results than IACI. However, the follow-up period was relatively short, and long-term prognostic differences were not observed[35]. No studies with longer follow-up periods have been conducted to investigate the progression of osteoarthritis and loss of functional scores after meniscal tears treated with intra-articular corticosteroid injection and APM.

The primary aim of this study was to analyze postoperative JSW changes between APM and IACI treatments for degenerative meniscal tears using OAI database data. The secondary objective was to compare postoperative clinical functional scores between the two treatment groups.

Methods

Data source

The data used in this study came from the publicly available Osteoarthritis Initiative (OAI) database, which is a publicly funded database sponsored by the National Institutes of Health (part of the Department of Health and Human Services) in the United States. The OAI is a ten-year, multi-center, longitudinal prospective observational study. The OAI database recruited 4,796 participants aged 45–79 at baseline, collected radiographic, clinical, and biological data, and recorded various data for each participant at each follow-up time point for the study of the occurrence and progression of osteoarthritis. The participant data primarily came from four research centers in the United States (The Ohio State University, Columbus, Ohio; University of Pittsburgh, Pittsburgh, Pennsylvania; Johns Hopkins University, Baltimore, Maryland; Brown University, Providence, Rhode Island). The participants included in the study had symptomatic tibiofemoral knee osteoarthritis or symptomatic risk at the start of the study, while participants with inflammatory arthritis, contraindications to 3T MRI, and bilateral end-stage knee osteoarthritis were excluded. Detailed inclusion and exclusion criteria for participants and participant data can be found on the OAI website (https://nda.nih.gov/oai). Based on the severity of osteoarthritis, the OAI database divided participants into three groups: (1) osteoarthritis progression group: symptomatic knee osteoarthritis, accounting for approximately 29% of the total number of participants; (2) possible osteoarthritis progression group: asymptomatic knee osteoarthritis in either knee but with a risk of progression to symptomatic knee osteoarthritis, accounting for approximately 68% of the total number of participants; (3) asymptomatic knee osteoarthritis without a risk of progression, accounting for approximately 3% of the total number of participants. The OAI dataset is a public database, and all patients provided informed consent upon joining the database. The OAI dataset is considered exempt by the ethics review board of the author's institution.

Research sample

For participants in the IACI group, we selected those with imaging-confirmed meniscal tears and who had received IACI treatment, based on the existing database analysis. Meniscal tears were defined as the presence of any of the following types: radial tears, horizontal tears, vertical tears, or complex tears. Additionally, we determined whether participants had received IACI by asking them at follow-up time points: 'Which knee joint received a corticosteroid injection (triamcinolone/corticosteroid) in the past 6 months?' If participants specified a knee joint, we defined that knee as having received IACI at that follow-up time point. We initially identified 212 participants in the IACI group. If participants specified which side of the knee joint, we defined it as receiving IACI at that follow-up time point. If patients received bilateral IACI treatment during the follow-up period, we excluded the left knee joint and included the right knee joint in this study ($n=20$). We excluded participants who underwent arthroscopic partial meniscectomy (APM) before baseline and during the follow-up period ($n=26$), underwent knee replacement surgery ($n=82$), lacked complete X-ray data ($n=16$), lacked period-specific Kellgren-Lawrence (KL) grading ($n=21$), and had KL grade 4 ($n=2$). Finally, we obtained the IACI group ($n=63$) (Fig. 1).

Regarding the APM group, we collected data from 251 participants in the OAI cohort who underwent APM during the follow-up period. We excluded participants who underwent multiple APM procedures ($n=30$), intra-articular corticosteroid injections ($n=34$), knee replacement surgery ($n=34$), lacked complete X-ray data and baseline KL grading ($n=70$). Finally, we obtained participants in the APM group ($n=83$). For the no intervention group after meniscal tear, we selected participants ($n=884$) from the OAI database who had observed meniscal tear at baseline. Participants who received IACI treatment during the follow-up period ($n=162$), underwent APM treatment during the follow-up period ($n=36$), underwent knee replacement surgery during the follow-up period ($n=77$), underwent knee surgery before the OAI study records ($n=44$), or lacked follow-up X-ray data ($n=102$) were excluded from the study population. Ultimately, we identified 450 participants in the no intervention group.

In this study, both case-control matching and propensity score matching (PSM) were used to match participants in the APM group and the non-treatment group with those in the IACI group. In the PSM procedure, matching was performed based on age (± 5 years), sex, BMI, race, KL grade, smoking status, and baseline MJSW,

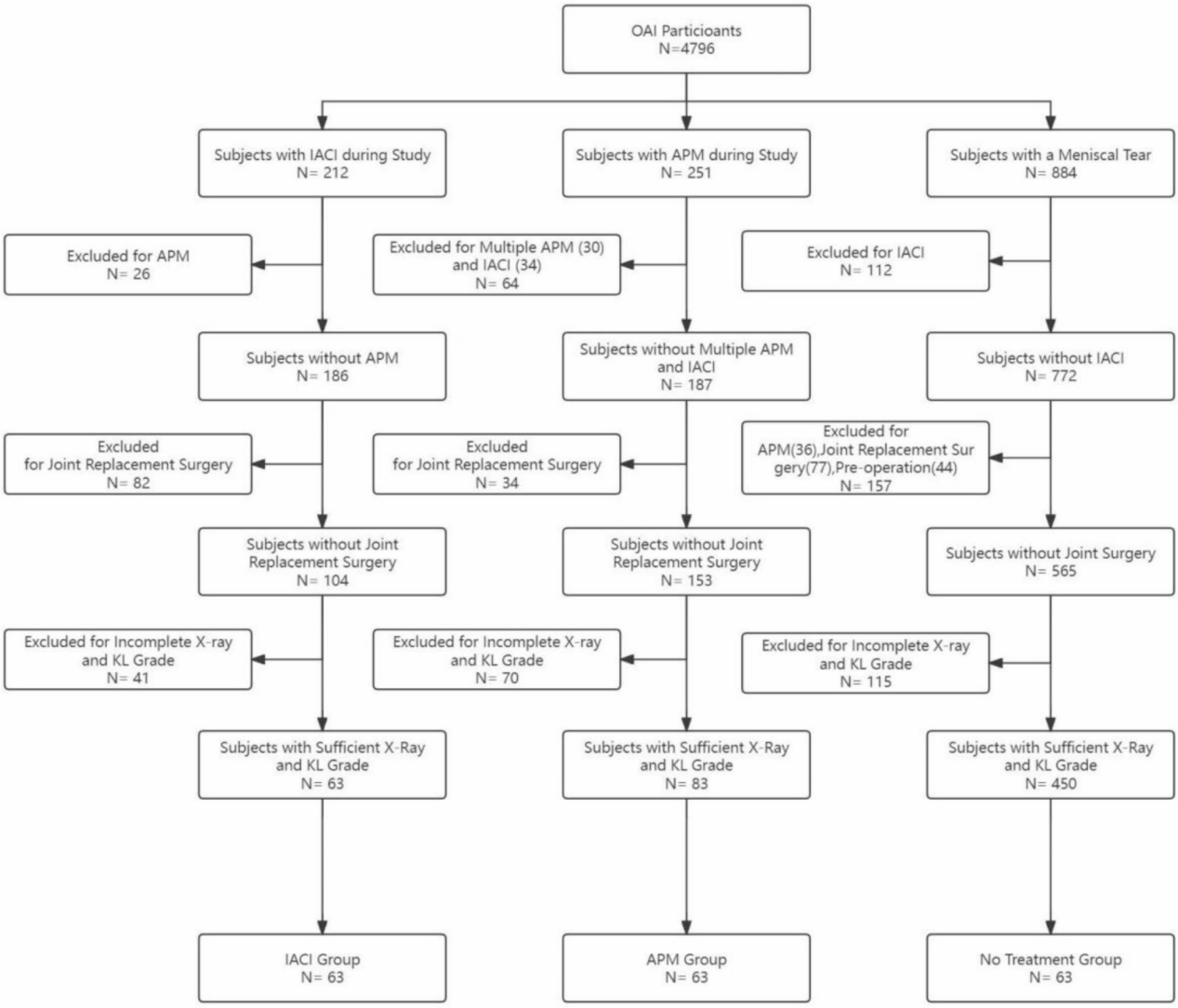

Fig. 1. Screening of study groups from the OAI cohort. OAI: Osteoarthritis Initiative; IACI: intra-articular corticosteroid injections; APM: arthroscopic partial meniscectomy; KL grade: Kellgren-Lawrence.

with a matching tolerance parameter of 0.02.We selected 63 participants from each group, resulting in a final APM group ($n=63$) and no intervention group ($n=63$).

Imaging evaluation

At baseline and follow-up time points, participants in this study underwent weight-bearing, fixed-flexion, posteroanterior knee X-ray examinations bilaterally. The minimum joint space width (JSW) of the medial compartment of the knee was measured using automated software at baseline and each follow-up time point[36]. We used KL grading data measured in the OAI database, which were determined by trained readers using consecutive X-ray radiographs[37].

Clinical questionnaires

This study used the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score to assess knee osteoarthritis symptoms in participants at each annual visit[38]. The WOMAC score is a standardized questionnaire that consists of three parts: pain (score: 0–20), stiffness (score: 0–8), and physical function (score: 0–68). A higher WOMAC score indicates more severe osteoarthritis symptoms.

To further assess long-term symptoms and function of knee osteoarthritis, we also selected the Knee injury and Osteoarthritis Outcome Score (KOOS). The KOOS score consists of five subscales: pain, symptoms, activities of daily living (ADL), sport and recreation function (Sport/Rec), and knee-related quality of life (QOL)[39]. Each subscale is scored from 0 to 100, with higher scores indicating better knee joint function. WOMAC scores and KOOS scores were both derived from the OAI database.

Statistical analysis

We used mean and standard deviation to describe continuous variables such as age, BMI, and JSW. We used percentages to describe categorical variables such as race, gender, smoking status, and KL grade. Analysis of variance and Fisher's exact test were used for statistical analysis of continuous and categorical variables, respectively.

To examine the relationship between JSW change rate over time and group pairs, we established a linear mixed-effects model. We included age, race, BMI, smoking status, KL grade, baseline JSW, group, time, and the interaction between group and time as fixed effects in the model, while adjusting for important covariates such as age, race, gender, BMI, smoking status, KL grade, and baseline JSW. We used independent sample T test to analyze the JSW change rate of patients with different BMI ranges.

We established a generalized estimating equation to study the differences in knee OA progression between participants receiving single IACI treatment and multiple IACI treatments. Important covariates such as age, race, gender, BMI, smoking status, KL grade, and baseline JSW were adjusted in the equation to mitigate the influence of covariates on the statistical results.

Statistical analysis was performed using SPSS (version 26), and a significance level of less than 0.05 ($p < 0.05$) was defined as having a statistically significant difference.

Result

Each group included 63 participants, with a total of 189 participants and 189 knee joints (Table 1). The mean age of the participants was 64.9 ± 8.6 years, and there were no statistically significant differences in age among the APM, no intervention, and IACI groups. The majority of the participants were female (over 50%) and white (approximately 82.5% of the total population), but there were no statistically significant differences in gender and race among the three study groups. The mean baseline JSW of the participants was 4.1 ± 1.3 mm, and there were no significant differences in baseline JSW among the groups. However, there were statistically significant differences in baseline WOMAC and KOOS scores among the groups, with participants in the IACI group generally having lower scores.

In the first 12 months, the JSW of patients in the IACI and APM groups decreased rapidly, from 4.1 ± 1.4 mm to 3.7 ± 1.5 mm and from 3.9 ± 1.2 mm to 3.4 ± 1.2 mm, respectively (Fig. 2). From 12 to 48 months, the rate of JSW decrease in both groups slowed down and tended to stabilize. At the end of the follow-up period, the JSW in the IACI and APM groups was 3.2 ± 1.3 mm and 3.2 ± 1.1 mm, respectively.

During the 48-month follow-up period, the rate of JSW decrease differed significantly among the three study groups (Table 2). The IACI group had the fastest rate of JSW decrease, with a rate of -0.020 mm/mo (95% CI: -0.027 to -0.013, $p < 0.01$), while the APM and no intervention groups had rates of -0.017 mm/mo (95% CI: -0.024 to -0.010, $p < 0.01$) and −0.013 mm/mo (95% CI: -0.020 to -0.007, $p < 0.01$), respectively. Although the rate of JSW decrease in the IACI group was faster than that in the APM group, the difference was not statistically significant (95% CI: -0.013 to 0.007, $P = 0.60$). In addition, BMI (regression coefficients: -0.012, 95% CI: -0.022 to 0.001, $p = 0.03$) and baseline JSW (regression coefficients: 0.939, 95% CI: 0.894 to 0.958, $p < 0.01$) were found to have significant effects on the rate of JSW decrease (Table 3).

The WOMAC total scores of patients in the IACI and APM groups decreased during the follow-up period, with rates of -0.123 score/mo (95% CI: -0.211 to -0.036, $p < 0.01$) and −0.115 score/mo (95% CI: -0.201 to -0.028, $p < 0.01$), respectively, but there was no statistically significant difference between the two groups ($P = 0.89$) (Table 4). The no intervention group showed an increasing trend in WOMAC total scores, with a rate of 0.015 score/mo, which was significantly higher than that of the IACI and APM groups ($P = 0.02$ and $P = 0.03$). We suspected that this may be related to the fact that patients in the no-treatment group had a higher BMI at baseline. Among the various factors, BMI (regression coefficients: 0.189, 95% CI: 0.008 to 0.370, $p = 0.04$) were found to significantly affect the WOMAC total scores of the patients (Table 5). Subscale analysis of WOMAC scores showed varying degrees of improvement in pain, stiffness, and physical function in the IACI and APM groups, while the no intervention group showed a worsening trend in the subscale scores compared to the baseline period (Table S1). BMI has a significant impact on the postoperative scores of all subscales of the WOMAC in patients (Table S2). During the follow-up period, the no intervention group showed a worsening trend in the KOOS subscale scores (pain and symptoms) (-0.039 score/mo and −0.014 score/mo), while the IACI and APM groups showed improvement in all subscale scores (Table S3). BMI was found to have a statistically significant effect on the symptom's subscale of KOOS ($P < 0.001$)(Table S4).

Finally, there was a significant difference in JSW between patients receiving single IACI treatment and those receiving multiple IACI treatments, with the single IACI group having less JSW decrease ($P = 0.04$) (Table S5). We further categorized all patients based on BMI and found that the rate of JSW decline in the BMI > 30 group was significantly higher than that in the BMI < 30 group ($P = 0.01$)(Table S6).

Discussion

In this present study, we found that patients with meniscal tears experienced JSW loss after both IACI and APM treatment, and the amount of JSW loss was greatest in the first 12 months, and the rate of JSW loss slowed in both groups after 12 months, but there was no statistical difference in JSW loss between the two treatments. In the IACI group, patients who received multiple injections experienced more JSW loss than those who received a single injection. At the end of the follow-up period, both the IACI group and the APM group showed improvement trends in their WOMAC and KOOS scores. In contrast, patients in the no-treatment group showed varying degrees of worsening of their WOMAC and KOOS scores, and there were statistically significant differences between the groups. This indicates that IACI therapy and APM therapy can improve patients' clinical function and quality of life to a certain extent. At the same time, this study demonstrates that

Characteristics	Total (*N* = 189)	IACI (*N* = 63)	APM (*N* = 63)	No treatment (*N* = 63)	*P*
Age mean (SD), y	64.9 (8.6)	66.4 (9.7)	63.3 (6.7)	64.9 (8.6)	0.12[b]
Sex, (%)					0.92[c]
Male	83 (43.9)	27 (42.9)	27 (42.9)	29 (46.0)	
Female	106 (56.1)	36 (57.1)	36 (57.1)	34 (54.0)	
BMI mean (SD), kg/m^2	29.6 (4.4)	29.3 (3.7)	29.6 (4.5)	29.8 (5.1)	0.87[b]
Race, (%)					0.93[d]
Other Non-white	3 (1.6)	1 (1.6)	1 (1.6)	1 (1.6)	
White	156 (82.5)	50 (79.4)	54 (85.7)	52 (82.5)	
African American	30 (15.9)	12 (19.0)	8 (3.2)	10 (15.9)	
Smoking status, (%)					0.88[d]
Never	91 (48.1)	32 (51.6)	27 (44.3)	32 (51.6)	
Current	10 (5.3)	4 (6.5)	3 (4.9)	3 (4.8)	
Former	84 (45.5)	26 (41.9)	31 (50.8)	27 (43.5)	
Baseline JSW mean (SD), mm	4.1 (1.3)	4.1 (1.4)	3.9 (1.2)	4.1 (1.4)	0.53[b]
Baseline KL grade, (%)					0.69[d]
Grade 0	18 (9.5)	4 (6.3)	9 (14.3)	5 (7.9)	
Grade 1	38 (20.1)	14 (22.2)	9 (14.3)	15 (23.8)	
Grade 2	70 (37.0)	23 (36.5)	24 (38.1)	23 (36.5)	
Grade 3	63 (33.3)	22 (34.9)	21 (33.3)	20 (31.7)	
Baseline WOMAC					
Pain score	3.6 (3.7)	3.9 (3.2)	3.3 (3.0)	3.8 (3.1)	0.51[b]
Stiffness score	1.8 (1.7)	2.0 (1.8)	1.9 (1.5)	1.5 (1.6)	0.75[b]
Disability score	10.9 (11.5)	11.6 (10.8)	10.6 (9.6)	10.5 (10.1)	0.85[b]
Total score	16.2 (16.2)	17.1 (18.1)	15.8 (13.1)	15.7 (13.5)	0.57[b]
Baseline KOOS					
Pain score	77.6 (18.6)	75.8 (19.6)	77.6 (16.3)	79.4 (15.6)	0.62[b]
Symptoms score	80.9 (17.6)	77.3 (18.9)	78.5 (15.9)	86.9 (14.8)	0.35[b]
ADL & Sport/Rec	66.6 (26.4)	63.2 (26.9)	67.9 (22.9)	68.7 (22.6)	0.85[b]
QOL	58.8 (21.8)	57.4 (19.1)	57.7 (19.9)	61.3 (22.6)	0.65[b]

Table 1. Summary of the characteristics of the research community[a]. [a]Summary of the characteristics of the research community. IACI: intra-articular corticosteroid injections; APM: arthroscopic partial meniscectomy; BMI: body mass index; JSW: joint space width; KL grade: Kellgren-Lawrence; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; KOOS: The Knee injury and Osteoarthritis Outcome Score; ADL: Function in daily living; Sport/Rec: Function in Sport and Recreation; QOL: knee-related Quality of Life. [b]Welch test. [c]Chi-square test. [d]Fisher's exact test.

BMI is an important factor that affects the prognosis of meniscus tears, which can simultaneously affect patients' knee JSW, WOMAC scores, and KOOS subscale scores.

Although IACI therapy is relatively safe in terms of systemic side effects, it can have a certain degree of damage to knee cartilage. Although cortisone has been reported to have beneficial effects on articular chondrocytes at low doses and short-term exposure, Mate analysis by Wernecke et al. reported that cortisone hormone has adverse effects on articular cartilage morphology and histology, especially at higher doses (> 3 mg/dose)[22]. The toxic effects of cortisone on cartilage are complex, possibly due to decreased aggrecan concentration in the knee cartilage of rabbits receiving IACI, as reported by Albano et al.[40] In several other studies, it was found that knees treated with IACI showed a reduction in cartilage volume and meniscus thickness compared to the control group[16,23].

Currently, most randomized controlled trials focus on the therapeutic effect of partial meniscectomy on degenerative meniscus tears, and there are few studies on the prognostic effect of IACI therapy on degenerative meniscus tears. In the study by Wilderman et al. ultrasound-guided IACI treatment was able to alleviate knee pain symptoms in patients with meniscus tears for approximately 5 weeks[41]. Similarly, studies by Byrne and Vermesan et al. found that IACI therapy can improve clinical symptoms in participants with degenerative tears of the medial meniscus posterior horn[35,42]. Our results also indicate that there was significant improvement in the WOAMC and KOOS scores of patients who received IACI during the follow-up period, but our study further investigated radiological changes in the knees. Compared to the no-treatment group, patients who received IACI had faster radiological OA progression in their knees.

Existing studies have shown that receiving multiple IACI treatments is more likely to lead to the progression of knee OA[22,24,43]. Studies by Werneke et al. have shown that higher doses of corticosteroids can cause damage

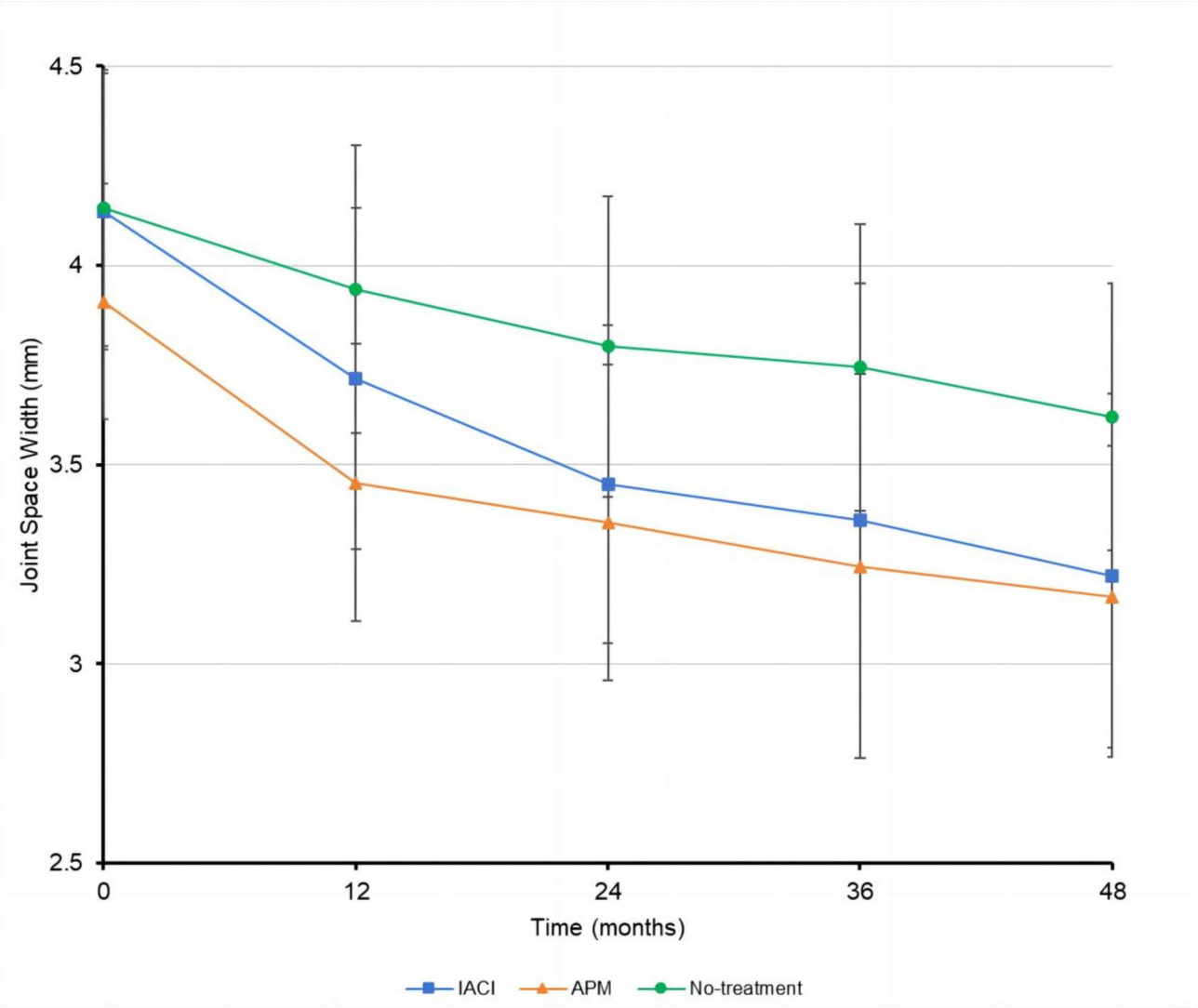

Fig. 2. Line graph of joint space width over time. Line graph of joint space width over time. IACI: intra-articular corticosteroid injections; APM: arthroscopic partial meniscectomy.

Label	Slope mm/mo	*P*
Slope: IACI group	− 0.020 (− 0.027 to − 0.013)	< **0.01**
Slope: APM group	− 0.017 (− 0.024 to − 0.010)	< **0.01**
Slope: no treatment group	− 0.013 (− 0.020 to − 0.007)	< **0.01**
Slope difference: IACI-APM	− 0.003 (− 0.013 to 0.007)	0.60
Slope difference: IACI-no treatment	− 0.006 (− 0.016 to 0.003)	0.19
Slope difference: APM-no treatment	− 0.004 (− 0.013 to 0.006)	0.45

Table 2. Rate of decline (slope) of JSW in each group during the follow-up period[a]. [a]Data are presented as 95% CI. IACI: intra– articular corticosteroid injections; APM: arthroscopic partial meniscectomy. Bold values indicate significance.

to chondrocytes[22]. Similarly, in another study using data from the OAI database, Zeng et al. found that patients who received multiple corticosteroid injections had an increased risk of radiographic OA in the knee compared to the control group[24]. The present study also confirmed this finding, showing that receiving multiple IACI treatments leads to a loss of knee joint space width (JSW). Furthermore, we found that compared to multiple IACI treatments, the group receiving a single IACI had less JSW loss in the knee joint. OAI did not record the dose of corticosteroids, but we speculate that high injection doses would exacerbate the worsening of OA in patients.

Factor	Regression Coefficients (95% CI)	*P*
Time	− 0.013 (− 0.020 to − 0.007)	**< 0.01**
Group: IACI vs. APM	− 0.069 (− 0.056 to − 0.193)	0.28
Group: IACI vs. no treatment	− 0.050 (− 0.170 to 0.071)	0.42
Group: APM vs. no treatment	− 0.108 (− 0.232 to 0.016)	0.07
Age	− 0.001 (− 0.007 to 0.005)	0.70
BMI	− 0.012 (− 0.022 to 0.001)	**0.03**
Sex: male vs. female	− 0.042 (− 0.136 to 0.052)	0.38
Smoking status: current vs. never	− 0.039 (− 0.259 to 0.180)	0.73
Smoking status: former vs. never	0.035 (− 0.062 to 0.133)	0.47
KL grade: 0 vs. 3	− 0.071 (− 0.278 to 0.135)	0.50
KL grade: 1 vs. 3	0.017 (− 0.133 to 0.167)	0.82
KL grade: 2 vs. 3	0.083 (− 0.047 to 0.212)	0.21
Baseline JSW	0.939 (0.894 to 0.958)	**< 0.01**
Time × group: IACI-APM	− 0.003 (− 0.013 to 0.007)	0.60
Time × group: IACI-no treatment	− 0.006 (− 0.016 to 0.003)	0.19
Time × group: APM-no treatment	− 0.004 (− 0.013 to 0.006)	0.45

Table 3. Results from a linear mixed-effects model of JSW over time[a]. [a]Data are presented as 95% CI. IACI: intra-articular corticosteroid injections; APM: arthroscopic partial meniscectomy; BMI: body mass index; KL grade: Kellgren-Lawrence; JSW: joint space width. Bold values indicate significance.

Label	Slope score/mo	*P*
Slope: IACI group	− 0.123 (− 0.211 to − 0.036)	**< 0.01**
Slope: APM group	− 0.115 (− 0.201 to − 0.028)	**< 0.01**
Slope: no treatment group	0.015 (− 0.067 to 0.098)	0.71
Slope difference: IACI-APM	− 0.009 (− 0.132 to 0.115)	0.89
Slope difference: IACI-no treatment	− 0.139 (− 0.260 to − 0.018)	**0.02**
Slope difference: APM-no treatment	− 0.130 (− 0.250 to − 0.011)	**0.03**

Table 4. Rate of decline (slope) of WOMAC total score in each group during the follow-up period[a]. [a]Data are presented as 95% CI. IACI: intra-articular corticosteroid injections; APM: arthroscopic partial meniscectomy; WOAMC: Western Ontario and McMaster Universities Osteoarthritis Index. Bold values indicate significance.

Previous studies have described the progression of radiographic OA in the knee after arthroscopic partial meniscectomy (APM), showing that there is a certain degree of JSW loss after APM treatment. Santana et al.'s study showed that patients who received APM treatment had more JSW loss and were more likely to experience joint space narrowing (JSN) compared to untreated meniscus tear patients[25]. Rongen et al. 's study, which included 62 patients, demonstrated that patients who underwent APM treatment had a greater degree of postoperative joint space narrowing, with an average decrease of 0.7mm[44]. However, APM treatment can significantly improve patients' clinical symptoms and quality of life[44]. In several randomized controlled trials, APM groups did not show clear short-term and medium-term advantages compared with physical therapy groups and "sham surgery groups", although patients receiving APM treatment had improved pain and other clinical symptoms[45–52]. A meta-analysis showed that there was no significant difference in pain improvement in patients with degenerative meniscal tears treated with APM compared with the non-surgical group[53]. Our study yielded similar results, showing that patients experience JSW loss after receiving IACI treatment, but their WOMAC and KOOS scores improved.

A randomized controlled trial involving 146 participants with medial meniscus tears showed that the APM group had greater radiographic OA progression compared to the sham surgery group[33]. Further studying the prognostic effects of APM and IACI, Vermesan et al.'s research showed that within one month of follow-up, arthroscopic surgery for meniscus tears had slightly better effects than IACI[35]. Our study extended the follow-up period and investigated the prognostic differences between IACI and APM treatments in patients with meniscus tears over 48 months. We found that both treatment methods relieved patients' clinical symptoms but also led to the progression of knee joint radiographic OA. Although the IACI group had faster JSW loss, there was no significant difference between the two groups.

There may be multiple reasons for the occurrence of knee joint JSW damage after IACI and APM. Corticosteroids may cause damage to chondrocytes by regulating the content of type II collagen and proteoglycans. Also, IACI can promote the progression of knee OA by reducing the thickness of the medial meniscus. Finally, at higher doses (> 3 mg/dose or 18–24 mg/total cumulative dose), corticosteroids exhibit significant chondrotoxicity, accelerating the progression of knee OA. APM can cause partial loss of the

Factor	Regression Coefficients (95% CI)	*P*
Time	0.015 (− 0.067 to 0.098)	0.71
Group: IACI vs. APM	2.314 (0.045 to 4.584)	**0.04**
Group: IACI vs. no treatment	3.132 (0.840 to 5.424)	**< 0.01**
Group: APM vs. no treatment	0.818 (− 1.401 to 3.036)	0.47
Age	− 0.004 (− 0.100 to 0.092)	0.94
BMI	0.189 (0.008 to 0.370)	**0.04**
Sex: male vs. female	− 0.353 (− 1.920 to 1.214)	0.66
Smoking status: current vs. never	− 1.725 (− 5.250 to 1.801)	0.34
Smoking status: former vs. never	− 0.151 (− 1.478 to 1.781)	0.86
KL grade: 0 vs. 3	− 2.183 (− 5.327 to 0.962)	0.17
KL grade: 1 vs. 3	− 0.776 (− 3.002 to 1.450)	0.49
KL grade: 2 vs. 3	0.078 (− 1.770 to 1.926)	0.93
Baseline Total	0.749 (0.694 to 0.805)	**< 0.01**
Time × group: IACI-APM	− 0.009 (− 0.132 to 0.115)	0.89
Time × group: IACI-no treatment	− 0.139 (− 0.260 to − 0.018)	**0.02**
Time × group: APM-no treatment	− 0.130 (− 0.250 to − 0.011)	**0.03**

Table 5. Results from a linear mixed-effects model of WOMAC total score over time[a]. [a]Data are presented as 95% CI. IACI: intra-articular corticosteroid injections; APM: arthroscopic partial meniscectomy; BMI: body mass index; KL grade: Kellgren-Lawrence; JSW: joint space width; WOAMC: Western Ontario and McMaster Universities Osteoarthritis Index. Bold values indicate significance.

meniscus, leading to knee joint instability and increased contact stress between the femoral condyle and tibial plateau, resulting in increased cartilage loss and accelerated progression of knee OA. The direct partial loss of the meniscus after APM may directly reduce knee joint space width. Partial cartilage damage during APM surgery may also contribute to the accelerated progression of knee OA during long-term follow-up. This situation is rare, and its impact on prognosis is controversial. In our study, BMI was an important factor affecting the prognosis of meniscus tears, with higher BMI associated with an increased risk of accelerated knee OA progression and worse clinical symptoms.

In retrospective studies on the treatment outcomes of degenerative meniscal tears, follow-up periods can range from 48 to 108 months[24,25,44]. Therefore, we recommend that, in retrospective studies, a follow-up duration of at least 48 months should be considered in order to comprehensively assess the long-term effects of treatment and observe the progression of joint degeneration. The OAI database primarily includes data from the U.S. population. Compared to China and other regions, cultural, lifestyle, genetic, and socioeconomic factors may influence the generalizability of the study results. For instance, Americans tend to have higher-calorie diets but also benefit from a more advanced healthcare system, which could affect the applicability of this research to East Asian populations, such as in China[54]. Therefore, we hope that patient data from regions such as Asia and Africa can be refined in future studies to increase the global applicability of the findings. However, we believe that for most regional populations, maintaining a healthy BMI plays a positive role in the treatment of degenerative meniscal tears. In future research, we aim to use patient data from our institution and actively collaborate with other medical institutions to obtain more long-term clinical data. Further studies will explore the mid- and long-term treatment effects of different therapeutic approaches for degenerative meniscal tears in populations from East Asian countries, such as China. This will provide more evidence to guide clinicians in China and other East Asian countries in selecting appropriate treatment methods.

This study has several limitations. (1) The data for this study came from observational research, which had limitations in the process of sample inclusion, resulting in a smaller number of patients in the final study group. Furthermore, due to the small number of patients, we did not conduct a classification study on the tear type. And because it is difficult to control for parameters that can influence disease progression (e.g., changes in BMI, disease onset, physical activity, etc.), study results may be affected by these confounding factors. Due to limitations in data type, time constraints, and other factors, we were unable to perform external validation with an independent dataset in this study. External validation is a critical step in ensuring the reliability and generalizability of research findings. The lack of external validation may impact the external validity of our results, particularly regarding their applicability in different regions or populations. In future studies, we hope to collaborate with other institutions or research teams to obtain external datasets for validating the findings of this study. (2) The IACI information in the OAI database was only assessed for the first 6 months of annual follow-up, and the IACI status of patients in the first half of the year was not recorded. Plus, the assessment of IACI participants in the OAI database relied on self-reporting, which may introduce recall bias. If this occurs, it could affect the research results on the impact of IACI on the progression of knee OA. (3) The OAI database did not record data on the type and dosage of corticosteroids, making it impossible to further study the impact of IACI type and dosage on knee OA in patients. (4) While the OAI has a wealth of valuable patient data, it does not specifically record the surgical indications determined by the surgeons for surgical treatment. Hence, the decision-making process of surgeons in the IACI group, APM group, and non-intervention group may differ. Patients in the IACI and APM groups may have more severe clinical symptoms compared to the non-intervention

group, leading them to receive more aggressive invasive treatment methods. (5) The follow-up period in this study was relatively short, only studying the mid-term treatment effects of the IACI and APM groups. Long-term progression of knee OA and improvement in clinical symptoms after treatment in patients need further research. (6) The OAI database mainly includes data on the American population. Compared with China and other regions, different lifestyles, genetics, and socioeconomic factors may affect the application of research results. However, knee osteoarthritis, as a common disease worldwide, especially in the elderly population, has a high degree of cross-cultural commonality. Further inclusion of other regional study populations could be included in future studies to increase the broad applicability of the findings.

Conclusion

It was found that the meniscal tear symptoms of IACI group and APM group were significantly improved. Patients with meniscal tears treated with IACI and APM had greater knee JSW loss than patients without treatment. JSW in IACI group and APM group decreased significantly in the first 12 months, and JSW decreased gradually in the subsequent time. Nonetheless, there was no statistical difference in the rate of JSW decline among groups. BMI is a major factor driving the deterioration of knee osteoarthritis in patients with degenerative meniscal tears following treatment. Regarding the treatment options for patients with degenerative meniscal tears, based on our study, we recommend that clinicians exercise caution when choosing APM as a treatment approach in patients without meniscal block. In contrast, IACI may be preferred due to its favorable outcomes in alleviating tear symptoms and restoring knee function. Additionally, IACI offers advantages in terms of lower cost and reduced risk compared to APM. Although populations in other regions such as China have differences in lifestyle and other aspects from the American population included in the OAI database, we also recommend maintaining a healthy BMI.

Data availability

The datasets generated during the current study are publicly available and accessible through the OAI (https://nda.nih.gov/oai).

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Author contributions

Substantial contributions to the conception or design of the work: H.R.Z and X.N.L. Acquisition of data, analysis or interpretation of data: All authors. Drafting the work or reviewing it critically for important intellectual content: X.N.L. Final approval of the version to be published: All authors. All authors read and approved the final manuscript.

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Declarations

Ethics approval
The OAI dataset is a public database, and all patients provided informed consent upon joining the database. The OAI dataset is considered exempt by the ethics review board of the author's institution.

Competing interests
The authors declare no competing interests.

Additional information
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