Original Article
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Clinical Impact of Meniscal Scaffold Implantation in Patients with Meniscal Tears: A Systematic Review

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Background: Meniscal scaffold implantation has been introduced as a treatment for meniscal injuries, but there is still no clear consensus on its clinical impact, including its chondroprotective effect. This review aimed to assess the chondroprotective effects, clinical outcomes, and survivorship of meniscal scaffold implantation compared to meniscectomy, as well as among different types of scaffolds.

Methods: A comprehensive search strategy was performed on the databases of PubMed, Embase, Cochrane Library, and Google Scholar, encompassing articles published until June 1, 2024. Randomized controlled trials (RCT) and comparative studies published in English that reported results using collagen meniscal implant (CMI) and polyurethane meniscal scaffold for meniscal tear were included.

Results: A total of 421 studies were initially identified across databases, and a systematic review was conducted on 8 studies involving 596 patients. Among the 5 studies that addressed the chondroprotective effect, none found that meniscal scaffolds had a higher chondroprotective effect compared to meniscectomy. In studies comparing CMI and meniscectomy, the Lysholm score results showed a mean difference (MD) range between –5.90 and –4.40. In the case of visual analog scale score, the MD ranged from –1.0 to 1.0. In studies comparing polyurethane meniscal scaffolds and CMI, the Tegner score results showed an MD range of –2.0 to 0.4.

Conclusions: There was no superiority in chondroprotective effects for both CMI and polyurethane meniscal scaffolds compared to meniscectomy. Although meniscal scaffolds may provide improvements in clinical outcomes, no clinically relevant differences were observed in comparison to meniscectomy. There are no discernible differences between the 2 types of scaffolds.

Keywords: *Meniscal scaffold implantation, Collagen meniscal implant, Polyurethane meniscal scaffold, Chondroprotective effect, Systematic review*

Meniscal injuries are prevalent in orthopedic practice and can significantly impact knee biomechanics due to the loss of meniscal tissue.[1-6] Although meniscal allograft transplantation (MAT) proves effective for complete meniscus replacement, MAT is not suitable for partial meniscal resection.[7-9] The decision to choose between MAT and meniscal scaffolds remains contentious. Moreover, MAT

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offers pain relief and improved knee function, but has high reoperation and failure rates.[10,11] On the other hand, meniscal scaffolds may offer better accessibility in the clinical field for partial resection cases, as they do not require a matching graft of the same size as MAT.[1,12] Meniscal scaffolds can generate fibrocartilage similar to the original meniscus.[1] The ongoing debate centers on determining whether MAT or meniscal scaffolds are significantly effective in delaying the onset of osteoarthritis.[13-15]

In addition to MAT, which was introduced in the 1980s, autologous tissue-based meniscal substitutions were also attempted.[16] However, despite some promising results in animal studies, no favorable clinical outcomes have been reported, and as a result, these methods have not become routine in clinical practice.[17] The development of meniscal scaffolds, which is the primary focus of this study, has advanced significantly as the understanding of meniscal biomechanics and tissue engineering has improved. These scaffolds rely less on their own mechanical properties and more on the ingrowth of fibrochondrocyte-like cells, which induces tissue formation and remodeling, ultimately resembling the biomechanical properties of the native meniscus.[18,19] Following this, meniscus prostheses such as the NUsurface Meniscus Implant (Active Implants), a discoid-shaped non-anatomical option, have also been introduced.[16]

Currently, only 2 types of scaffolds are available in clinical practice, collagen meniscal implant (CMI; Stryker Corp.) and polyurethane meniscal scaffold (Actifit, Orteq).[20,21] The CMI, clinically introduced in 1997, was the first meniscal substitute for treating partial meniscal defects. The CMI consists of type I bovine collagen and glycosaminoglycan, making it arthroscopically implantable, biocompatible, and bioresorbable. Long-term clinical studies have demonstrated a significant enhancement in knee function and pain reduction with the use of CMI.[12,22-24] However, collagen scaffolds remain susceptible to fragility during implantation procedures and may exhibit size reduction, as observed in radiographical evaluation and second-look arthroscopy results.[25]

In contrast, the polyurethane meniscal scaffold presents a slowly biodegradable, synthetic, acellular structure composed of polycaprolactone and urethane segments.[26] Polycaprolactone exhibits durability for up to 5 years and undergoes degradation via ester bond hydrolysis, while in comparison, urethane offers greater stability, being either phagocytized by macrophages or integrated into the surrounding tissue.[27] This scaffold is notably more resistant to surgical procedures and loads; however, long-term follow-up studies are still lacking.[28] As of now, no conclusive evidence is present supporting the superiority of one scaffold over the other.

Recently, several systematic reviews have investigated the use of meniscal scaffolds. The study by Reale et al.[28] revealed that both CMI and polyurethane meniscal scaffolds yielded positive clinical results, including significant and comparable improvements in symptoms and function, as well as a low incidence of failures over time. Notably, they identified no differences in clinical outcomes between CMI and polyurethane meniscal scaffolds. Bian et al.[29] stated that while tissue-engineered meniscal implants may provide short-term improvements in knee symptoms and function, no implant has demonstrated significant long-term benefits for meniscus defects.

Among these, the relatively recent study by Bian et al.[29] included all studies with a level of evidence of 4 or higher, but only analyzed papers published since 2016. However, to address the comparative effectiveness of treatments with similar indications to meniscal scaffolds, such as meniscectomy, there is a need for a systematic review of comparative studies with a level of evidence of 3 or higher. Additionally, the authors saw a need for a review on the chondroprotective effect, which is one of the most important roles of meniscal scaffolds. Given this background, this systematic review was conducted.

The present study aimed to systematically review the current literature, providing an updated assessment of the evidence regarding the chondroprotective effects, clinical outcomes, and survivorship associated with meniscal scaffold implantation treatments. In particular, it sought to compare the therapeutic effectiveness of meniscectomy, which is performed for the treatment of partial meniscal tears, with meniscal scaffold implantation, as well as to compare the therapeutic effectiveness among different types of meniscal scaffolds. We hypothesized that meniscal scaffolds would be superior to meniscectomy in the aspects mentioned above and that there would be no significant differences among the different types of meniscal scaffolds.

METHODS

Search Strategy

This review was preregistered in the PROSPERO prospective register of systematic reviews and conducted following a predefined protocol, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. A comprehensive search strategy was devised to identify relevant studies, involving a systematic search of databases such as PubMed, Embase, Cochrane

Library, and Google Scholar, encompassing articles published until June 1, 2024. The search was conducted using the following search parameters: ("Meniscus" OR "meniscal") AND ("scaffold" OR "implant" OR "substitute" OR "synthetic" OR "artificial"). Moreover, the search was limited to studies published in the English language.

Identification of Eligibility

The inclusion criteria were as follows: (1) studies targeting patients with meniscal tears or defects; (2) studies that included interventions with CMI or polyurethane meniscal scaffold reporting clinical efficacy; (3) studies with a minimum follow-up period of 2 years; and (4) randomized controlled trials (RCTs) and prospective or retrospective comparative studies published in English. The exclusion criteria were as follows: (1) non-English articles; (2) studies with incomplete data; and (3) level 4–5 studies, animal studies, review articles, meta-analyses, case reports, and conference abstracts. Two independent reviewers screened the search results to determine eligibility.

Data Extraction

Two independent reviewers collected data, including the primary author, publication year, country of origin, study design, level of evidence, specific meniscal scaffolds under comparison, type of concomitant procedure, sample size, duration of follow-up, sex distribution, age, body mass index, preoperative and postoperative Lysholm scores, International Knee Documentation Committee (IKDC) scores, Tegner scores, visual analog scale (VAS) measurements, documented chondroprotective effects, and survivorship. For studies presenting results solely in graphical form without accompanying numerical values, we adopted the approach outlined by Gheibi et al.[30] to derive numerical data for analysis.

Generally, the level of evidence for a systematic review is determined by the level of evidence of the studies included in the review. However, due to the limited number of RCTs published on this topic to date, this study set the inclusion criteria to encompass all comparative studies, which consequently included studies with relatively lower levels of evidence. Given these concerns, we placed significant importance on assessing the risk of bias. To assess the risk of bias, we used the methodological index for non-randomized studies (MINORS),[31] consisting of 12 categories for comparative studies and 8 categories for non-comparative studies. Each category received a rating of 0 (if not reported), 1 (if reported but inadequate), or 2 (if reported and deemed adequate). The quality of the journals included in this review was further evaluated using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool.[32]

Statistical Analysis

Descriptive statistics, including mean and standard deviation for numerical variables, were documented. When studies lacked standard deviation in their results, we computed it based on other provided statistical values, following the method outlined by Furukawa et al.[33] For the analysis of continuous outcome measures, we utilized the mean differences (MD) with 95% CIs. Heterogeneity was assessed using the I^2 statistic. Pooled synthesis was avoided, considering heterogeneity between included studies and the level of evidence of studies included in this review. Forest plots were presented for outcomes covered by 3 or more studies included in this review. All statistical analyses and data visualization were performed using the R software (version 4.2.1; R Foundation).

RESULTS

Characteristics of Included Studies

In this systematic review, a total of 421 relevant studies were initially identified across various databases. After removing duplicates and reviewing the full texts, 37 studies were evaluated for eligibility. Finally, we included 8 studies involving 596 patients who met our inclusion criteria (Fig. 1).[8,25,34-39] The characteristics of the included studies are provided in Tables 1 and 2.

Methodological Quality Assessment of Included Studies

We assessed the methodological quality of the selected studies, identifying different levels. Two studies were classified as level 1,[38,39] 3 as level 2,[34,36,37] and 3 as level 3.[8,25,35] The average MINORS score was 21.1 ± 2.0. Further details on the MINORS scores are provided in Supplementary Table 1. The assessed ROBINS-I items are detailed in Supplementary Table 2.

Chondroprotective Effects

The chondroprotective effects of the meniscal scaffolds were evaluated in 5 studies using various methods, including magnetic resonance imaging (MRI) follow-up, second-look arthroscopy, and histologic evaluation.[8,25,34,37,38] Sabater-Martos et al.[34] compared the results of meniscectomy and polyurethane meniscal scaffold in the preoperative and postoperative MRIs of 19 cases, with a median time between surgery and postoperative MRI of 7 years (range, 4–9 years). The study identified no statistical significance between groups on Whole-Organ Magnetic Resonance

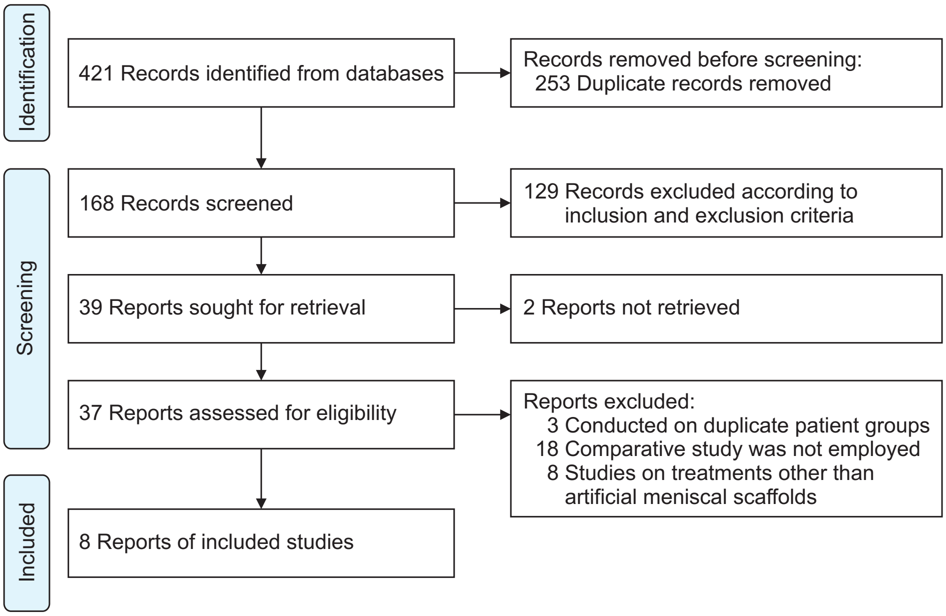

Fig. 1. Flow diagram for the systematic review following Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.

Table 1. Overview of Included Studies

Study	Year	Journal	Country	Study design	Level of evidence	Meniscal scaffolds	Number of patients	Combined procedures
Sabater-Martos et al.[34]	2023	*Arch Orthop Trauma Surg*	Spain	Prospective cohort study	II	Meniscectomy vs. polyurethane	30	ACLR
Reale et al.[35]	2022	*Arthroscopy*	Italy	Case-control comparative study	III	Collagen vs. polyurethane	47	ACLR, HTO, DFO, cartilage procedure
Bulgheroni et al.[25]	2016	*Cartilage*	Italy	Cohort study	III	Collagen vs. polyurethane	53	Tibial osteotomy, ACLR, MFX, healing response, suture
Gelber et al.[36]	2015	*Knee Surg Sports Traumatol Arthrosc*	Spain	Prospective comparative study	II	Meniscectomy vs. polyurethane	60	HTO
Spencer et al.[8]	2012	*Knee*	UK	Cohort study	III	Collagen vs. polyurethane	23	HTO, DFO, ACLR, LCLR, MFX
Zaffagnini et al.[37]	2011	*Am J Sports Med*	Italy	Prospective cohort study	II	Meniscectomy vs. collagen	33	ACLR
Rodkey et al.[38]	2008	*J Bone Joint Surg Am*	US	Randomized controlled trial	I	Meniscectomy vs. collagen	311	ACLR
Linke et al.[39]	2007	*Eur J Trauma Emerg Surg*	Germany	Randomized controlled trial	I	Meniscectomy vs. collagen	39	Correctional osteotomy

ACLR: anterior cruciate ligament reconstruction, HTO: high tibial osteotomy, DFO: distal femoral osteotomy, MFX: microfracture, LCLR: lateral collateral ligament reconstruction.

Imaging Score.[40]

Two studies compared the outcomes of meniscectomy and CMI.[37,38] Zaffagnini et al.[37] reported encouraging Yulish score[41] results for the CMI group at the 10-year follow-up (2 ± 1.5 for CMI and 3 ± 1.25 for partial meniscectomy) compared to those of meniscectomy, starting from comparable preoperative levels (2 ± 1.5 for CMI and 2 ± 1 for partial meniscectomy). However, these differences were not statistically significant ($p = 0.122$). In the study by Rodkey et al.[38] comparing meniscectomy and CMI, only the results of the CMI group that underwent second-look arthroscopy were reported. At the index sur-

Table 2. Characteristics of Patient Demographics of Included Studies

Meniscal scaffolds	Study	Follow-up duration	Sex (male : female)	Age (yr)	BMI (kg/m^2)
Meniscectomy vs. polyurethane	Sabater-Martos et al. (2023)[34]	83.5 mo (Polyurethane), 88.2 mo (meniscectomy)	10 : 2 (Polyurethane), 18 : 0 (meniscectomy)	31.8 ± 19.7 (Polyurethane), 34.2 ± 15.8 (meniscectomy)	23.9 ± 2.4 (Polyurethane), 23.1 ± 3.03 (meniscectomy)
	Gelber et al. (2015)[36]	31.2 mo (range, 24–47.5 mo)	19 : 11 (Meniscectomy), 21 : 9 (polyurethane)	51.2 ± 7.3 (Meniscectomy), 45.1 ± 8.3 (polyurethane)	25.6 ± 5.9 (Meniscectomy), 26.2 ± 2.7 (polyurethane)
Meniscectomy vs. collagen	Zaffagnini et al. (2011)[37]	133 mo	17 : 0 (Meniscectomy), 16 : 0 (collagen)	38 (Meniscectomy), 44 (collagen)	25.24 ± 1.65 (Meniscectomy), 26.03 ± 1.88 (collagen)
	Rodkey et al. (2008)[38]	59 mo (range, 16–92 mo)	126 : 34 (Collagen), 117 : 34 (meniscectomy)	39 (Collagen), 40 (meniscectomy)	NR
	Linke et al. (2007)[39]	2 yr	NR	41.6 (range, 19–68)	NR
Collagen vs. polyurethane	Reale et al. (2022)[35]	130.0 ± 7.8 mo (polyurethane), 125.1 ± 11.5 mo (collagen)	14 : 8 (Polyurethane), 17 : 8 (collagen)	44.1 ± 12 (Polyurethane), 42.4 ± 10.4 (collagen)	25.2 ± 3.4 (polyurethane), 25.2 ± 3.9 (collagen)
	Bulgheroni et al. (2016)[25]	2 yr	19 : 9 (Collagen), 20 : 5 (polyurethane)	38.7 ± 9.7 (Collagen), 34.4 ± 11.4 (polyurethane)	NR
	Spencer et al. (2012)[8]	24.1 mo (collagen), 14.7 mo (polyurethane)	NR	32 (Collagen), 39 (polyurethane)	NR

BMI: body mass index, NR: not reported.

gery, the mean Outerbridge score was 1.3 points and 1.5 points for patients in the acute and chronic CMI groups, respectively. At the 1-year second-look arthroscopy, the mean Outerbridge score remained at 1.3 points in both the acute and chronic groups. Although a slight improvement was observed in the chronic CMI group, it did not reach statistical significance.

Two studies compared the clinical outcomes of CMI and polyurethane meniscal scaffold.[8,25] Bulgheroni et al.[25] reported that no evolution of degenerative joint disease was observed over time for both polyurethane meniscal scaffold (p = 0.708) and CMI (p = 0.892). Second-look arthroscopy revealed intact articular cartilage without signs of progression of existing articular injury in the majority of patients in both groups. Histological analysis with light microscopy revealed that the implant was present, more compact, and filled with new tissue, and extracellular matrix deposited in a heterogeneous manner in both groups. In the study by Spencer et al.,[8] follow-up MRIs were performed in all 23 cases at a mean of 19 months after surgery. The study detected no progression of chondral wear following surgery on subsequent scans.

Clinical Outcomes

Each study compared clinical outcomes using various patient-reported outcome measures, and the clinical scores reported in this study are summarized in Table 3. Two studies compared meniscectomy with polyurethane meniscal scaffolds.[34,36] Sabater-Martos et al.[34] reported results for the Tegner score, Lysholm score, and Knee injury and Osteoarthritis Outcome Score (KOOS), indicating that only the Lysholm score showed a significant difference between the groups. There was a substantial score increase between the preoperative evaluation and the 5-year follow-up evaluation in favor of the meniscectomy group. Gelber et al.[36] observed improvement in Western Ontario Meniscal Evaluation Tool (WOMET), IKDC, and VAS for both treatment methods, but reported that the improvement in WOMET and VAS after meniscectomy was significantly greater.

Meniscectomy and CMI were compared in 3 studies.[37-39] Forest plots depicting the Lysholm score (Fig. 2A) and VAS (Fig. 2B) reported in these studies were presented. The Lysholm score results showed an MD range of –5.90 to –4.40, with all 3 studies favoring CMI over meniscectomy. Low heterogeneity was observed for the Lysholm score (I^2 = 33%, τ^2 = 0.3558, p = 0.23). Considering this, the Lysholm score consistently favored CMI over meniscectomy to some extent. In the case of VAS, the MD ranged from –1.0 to 1.0; the study by Zaffagnini et al.[37] showed results favoring CMI, but the other 2 studies[38,39] favored meniscectomy. This mixed trend showed substan-

Table 3. Clinical Scores in Included Studies

Study	Treatment group	Lysholm score		IKDC score		Tegner score		VAS	
		Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
Sabater-Martos et al. (2023)[34]	Polyurethane	68.6	88.9	NR	NR	3.1	5.4	NR	NR
	Meniscectomy	50.4	84.5	NR	NR	2.4	4.8	NR	NR
Gelber et al. (2015)[36]	Polyurethane	NR	NR	19.1 ± 5.9	69.4 ± 15.6	NR	NR	7.2 ± 1.1	2.5 ± 2.1
	Meniscectomy	NR	NR	20.1 ± 4.4	76.8 ± 15	NR	NR	7.9 ± 1	2.1 ± 1.9
Bulgheroni et al. (2016)[25]	Collagen	57.3 ± 16.9	94.1 ± 8.2	NR	NR	3	6	53.3 ± 30.8	14.7 ± 18.7
	Meniscectomy	61.1 ± 13.4	95.5 ± 7.6	NR	NR	3	6	38.4 ± 33.5	13.5 ± 16.2
Zaffagnini et al. (2011)[37]	Collagen	51.9 ± 10	91.7 ± 11.4	NR	NR	1 ± 1.5	4 ± 1.5	6 ± 1.1	1.2 ± 0.9
	Meniscectomy	44.1 ± 4.7	79 ± 8.1	NR	NR	1 ± 0.3	3 ± 1.2	7 ± 1.3	3.2 ± 1.8
Rodkey et al. (2008)[38]	Collagen	20.8	84.3	NR	NR	NR	NR	17	12.3
	Meniscectomy	25.3	82.9	NR	NR	NR	NR	19.6	12.9
Linke et al. (2007)[39]	Collagen	65.2	93.6	60.3	83	NR	NR	4.9	2.2
	Meniscectomy	67	91	53	77	NR	NR	5.2	1.5
Reale et al. (2022)[35]	Collagen	3.2 ± 1.1	3.8 ± 1	46.8 ± 16.7	62.1 ± 22.6	3.2 ± 1.1	3.8 ± 1	4.4 ± 1.7	2.7 ± 2.4
	Polyurethane	2 ± 1.2	3 ± 0.7	42.9 ± 5.9	67.4 ± 12.4	2 ± 1.2	3 ± 0.7	5.4 ± 2.3	3.4 ± 2.5
Bulgheroni et al. (2016)[25]	Collagen	58.4 ± 17.3	94.5 ± 6	NR	NR	2	5.2	NR	NR
	Polyurethane	67 ± 15.7	90.3 ± 13.1	NR	NR	4	5	NR	NR
Spencer et al. (2012)[8]	Collagen	61.8	82.9	48.1	71.8	3.7	5.2	NR	NR
	Polyurethane	56.5	86.6	42.1	74	3.8	4.4	NR	NR

Values are presented as mean ± standard deviation.
IKDC: International Knee Documentation Committee, VAS: visual analog scale, Preop: preoperative, Postop: postoperative, NR: not reported.

tial heterogeneity for VAS ($I^2 = 97\%$, $\tau^2 = 0.9716$, $p < 0.01$), indicating that it was difficult to find a consistent trend among the studies included in the review for VAS.

Upon reviewing the findings from each study, Zaffagnini et al.[37] reported that compared to partial meniscectomy, CMI resulted in significantly lower VAS and higher objective IKDC, Teger index, and Short Form Health Survey scores. Rodkey et al.[38] found no significant differences in the mean pain, Lysholm, and self-assessment scores between treatment groups, but noted that in the chronic group, patients who received CMI regained significantly more of their lost activity compared to the meniscectomy group. Linke et al.[39] reported only slight, non-significant differences in Lysholm Score and IKDC score after 24 months between the CMI and meniscectomy groups.

Polyurethane meniscal scaffolds and CMI were compared in 3 studies.[8,25,35] Forest plots depicting the Tegner score (Fig. 2C) reported in these studies were presented. The Tegner score results showed a MD range of –2.0 to 0.4; the study by Reale et al.[35] showed results favoring polyurethane meniscal scaffolds, while the other 2 studies[8,25] favored CMI. Considering the noted substantial heterogeneity ($I^2 = 100\%$, $\tau^2 = 1.4496$, $p < 0.01$), it was difficult to draw a consistent conclusion regarding the superiority of one treatment over the other in terms of the Tegner score.

When examining the findings from each study, Reale et al.[35] reported improvements in IKDC, VAS, and Tegner scores at the final follow-up, but found no significant differences in the scores between the 2 treatment groups. Bulgheroni et al.[25] observed improvements in Lysholm and Tegner score at the final follow-up, but the intergroup difference was not statistically significant. Spencer et al.[8] reported a significant improvement in the mean Lysholm, IKDC, and KOOS scores at follow-up compared to preoperative levels. The Tegner score had

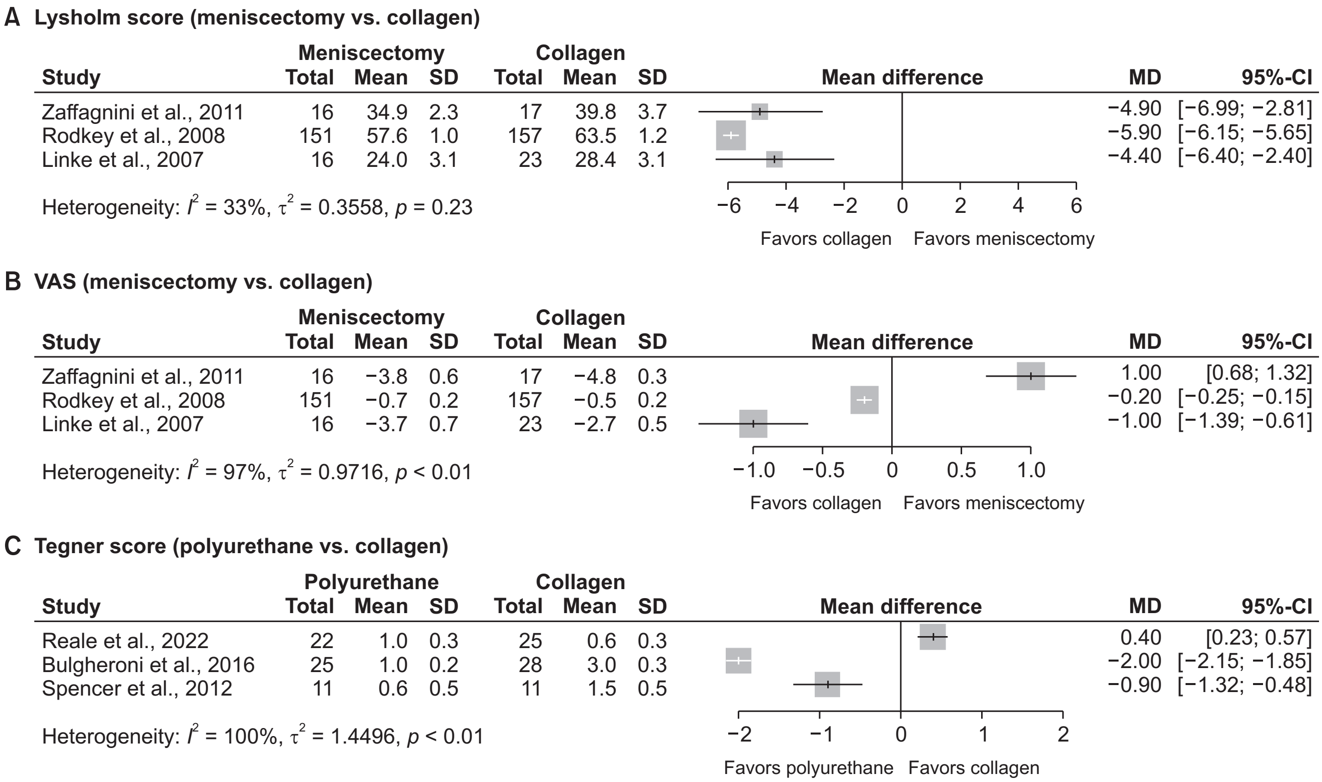

Fig. 2. Forest plot illustrating the differences in treatment effects on clinical scores for each treatment approach. The comparison between meniscectomy and collagen meniscal implant (CMI) is presented for Lysholm score (A) and visual analog scale (VAS) (B). (C) The comparison between polyurethane meniscal scaffold and CMI is depicted for Tegner score. SD: standard deviation, MD: mean difference.

improved following surgery, but did not reach a statistically significant level. Statistical differences between the 2 groups in terms of clinical outcomes were not reported.

Survivorship

The survivorship of the meniscal scaffolds was evaluated in 3 studies.[35,37,38] In the study by Rodkey et al.[38] comparing CMI and meniscectomy over 5 years within the chronic study group, the finding revealed a reoperation rate of 9.5% for patients who received a CMI and 22.7% for those who underwent meniscectomy. Consequently, the likelihood of reoperation was 2.7 times higher in the meniscectomy group compared to the CMI group (95% CI, 1.2–6.7; p = 0.04). In the acute study group, no discernible differences in reoperation and survival rates were observed between the 2 treatment modalities. This highlights the difference in reoperation rates between the chronic and acute groups when comparing meniscectomy to CMI. Moreover, there was a report of 1 acute collagen meniscus implant being explanted early due to mechanical failure. Zaffagnini et al.[37] also reported survival rates for CMI and meniscectomy, indicating that reoperations were necessary for 2 patients in each group (13%) during the follow-up period, with no statistically significant differences observed. One patient in the CMI group experienced swelling and pain, assumed to be related to the device, and was treated with arthroscopic debridement and high tibial osteotomy. Reale et al.[35] reported survival rates for polyurethane meniscal scaffold and CMI. Over a 10-year follow-up, 10 implants, with 5 in each group, required reoperation due to classifiable failures related to symptoms of the meniscal defects. This resulted in a cumulative failure rate of 21.3%, with no significant disparities noted between the 2 scaffold groups. They also conducted a survival analysis based on whether osteotomy was performed in addition to the scaffold, but no statistically significant differences in survivorship were observed.

DISCUSSION

The key finding of this review, based on the currently available studies, is that the chondroprotective effects of meniscal scaffolds remain uncertain. While there are improvements in clinical outcomes at follow-up points, particularly with a tendency favoring CMI over meniscectomy in the case of the Lysholm score, the distinctions of meniscal scaffolds compared to meniscectomy are not definitively established for other clinical outcomes. In terms of the need for reoperation, there appears to be potential improvement compared to meniscectomy, but the evidence is not sufficient. The differences between the 2 types of scaffolds were not confirmed in all aspects covered by this review.

Given that the function of the meniscus is to absorb weight-bearing stress on the knee joint and prevent cartilage degeneration, one of the most crucial roles attributed to meniscal scaffolds is considered chondroprotective.[42)] Meniscal scaffolds are commonly used to compensate for the loss of meniscal function that occurs after the frequently performed procedure of partial meniscectomy. Specifically, as reported in the study by Sabater-Martos et al.,[34)] in the case of polyurethane meniscal scaffolds included in this review, total resorption of the scaffold and meaningful Genovese Type I were confirmed in 3 out of 11 cases. This aligns with the results reported in another study, which documented a 38% full resorption of polyurethane meniscal scaffolds at 8 years in a cohort of 18 cases.[43)] Although not statistically significant, the study also reported a trend of increased resorption in older aged subjects.

In 2 papers that addressed chondroprotective effects comparing CMI and meniscectomy, Yulish score on follow-up MRI and Outerbridge grade on second-look arthroscopy were used.[37,38)] Similar to polyurethane, no clear differences between meniscectomy and CMI were observed in terms of cartilage deterioration. Specifically, Zaffagnini et al.[37)] also reported no difference in Genovese score at follow-ups of 5 and 10 years, indicating that while scaffold resorption occurs to some extent in the initial period after surgery, the degree of resorption remains stable after a certain point. These findings, along with the age-related trends presented by Sabater-Martos et al.,[34)] suggest the need for further research on the causes of scaffold resorption that may lead to the loss of chondroprotective effects.

One of the important purposes of a meniscal scaffold is its chondroprotective effect, which has also been mentioned in other studies not included in this review. Zur et al.[44)] reported on the chondroprotective effect of polycarbonate-urethane meniscus using a sheep model, showing histopathological results indicating that meniscus implant could counter the occurrence of major degenerative cartilage changes. However, in human applications, different tendencies were observed, as reported in the following studies. Bulgheroni et al.[45)] reported that the use of CMI, performed alongside anterior cruciate ligament reconstruction, did not influence radiologic evaluation using the Kellgren-Lawrence grade and Ahlbäck score. Similarly, Monllau et al.[22)] assessed CMI using the Ahlbäck score, and reported that the chondroprotective effect of CMI is unclear. A recent systematic review by Kohli et al.[46)] also reported that there is limited evidence of the chondroprotective effects of CMI and polyurethane meniscal scaffolds.

Most of the RCTs conducted so far have focused on the clinical outcomes or survivorship. In studies evaluating chondroprotective effects, various patient factors appeared to influence the results. Moreover, the chondroprotective effect has been evaluated using different methods across studies, making pooled analysis challenging. Therefore, high-quality RCTs focusing on this topic or meta-analyses of multiple comparative studies using the same evaluation method for chondroprotective effects should be conducted in the future.

In terms of clinical scores, both meniscal scaffolds and meniscectomy generally demonstrated improved results at follow-up points, but the extent of improvement varied. As shown in Fig. 2A, the Lysholm score exhibited relatively low heterogeneity, consistently favoring collagen over meniscectomy. However, considering that the minimal clinically important difference (MCID) for Lysholm score is 8.[9,47)] the observed MD in each study falls within the MCID range, making it challenging to deem it clinically relevant.

Moreover, VAS and Tegner scores (Fig. 2B and C) showed high heterogeneity, indicating inconsistent results. The cause of this heterogeneity seems to be related to the diverse concurrent procedures performed in each study, as observed in Table 3. Since it is challenging to accurately calculate the contribution of each procedure to the improvement in clinical outcomes, the varied results may be attributed to this factor. Additionally, the inclusion of non-randomized studies in this analysis could also contribute to the observed heterogeneity. Therefore, regarding clinical scores, it can be concluded that the use of meniscal scaffolds may provide improvement in clinical scores at follow-up points, but when compared to meniscectomy, clinically relevant superiority is not evident. Further investigation is warranted through future high-level evidence studies and subsequent meta-analyses to derive more conclusive findings.

Regarding survivorship, apart from the study by Rodkey et al.[38)] reporting a significantly lower reoperation rate for CMI compared to meniscectomy in a subgroup of patients with prior surgical procedures on the involved meniscus, no significant differences were reported in other studies. The reasons for reoperation are crucial to discuss, where one acute collagen meniscus implant was explanted early due to mechanical failure, leading to reoperation. In the study by Zaffagnini et al.,[37)] cases were reported where arthroscopic debridement was performed due to pain and swelling related to high tibial osteotomy. Reale et al.[35] reported reoperation cases involving knee arthroplasty and MAT due to persistent pain. Taken together, to reduce the reoperation rate, which can be considered a failure of treatment, improvements should be made to prevent mechanical failure of meniscal scaffolds and enhance chondroprotective effects.

In a recent systematic review on meniscal scaffolds, Bian et al.[29] reported that although these scaffolds may provide short-term improvements in knee symptoms and function, no implant has demonstrated significant long-term benefits for meniscus defects. Kohli et al.[46] stated that relying on meniscal scaffolds as the sole treatment for partial meniscal defects cannot be recommended due to a relatively high failure rate and limited clinical data. The present study, by consolidating existing research on meniscal scaffolds up to the present, presents updated information and aligns its conclusions with previous reviews regarding clinical outcomes and survivorship. The strength of this study lies in conducting a systematic review of studies with a relatively higher level of evidence compared to previous reviews, thereby providing evidence based on comparative effectiveness. Additionally, the consistency of its findings with prior systematic reviews reinforces the conclusions and serves as a stepping stone for future systematic reviews or meta-analyses involving more publications. Another strength of this study is its focus on chondroprotective effects, particularly in comparison with the commonly performed surgery of meniscectomy, which provides insights into areas for improvement in the development of future meniscal scaffolds.

This study has several limitations that should be considered when interpreting the results. First, due to a scarcity of high-level evidence studies on the topic covered in this review, studies with a relatively lower level of evidence were also included. To minimize the risk of bias in this context, the review focused on studies with a level of evidence of 3 or higher, allowing for comparative effectiveness analysis. However, this topic is ultimately more suitable for a network meta-analysis, which would require pooling data from future RCTs. Second, many studies included in the analysis had relatively short to medium-term follow-up periods. Long-term outcomes, particularly related to survivorship and the development of osteoarthritis, are crucial but may not have been adequately addressed in the included studies. Third, patient-specific factors, such as age, activity level, the degree of underlying chondrosis in the respective compartments, and concomitant procedures, may have a significant impact on the treatment outcomes. Therefore, caution is needed when accepting the conclusions of each study. Fourth, despite assessing chondroprotective effects through various methods, establishing the long-term impact on delaying osteoarthritis remains a challenge based on available literature. Further high-quality, long-term studies are needed to provide more robust evidence on the comparative effectiveness of meniscal scaffold treatments, their impact on knee biomechanics, and their role in preventing the development of osteoarthritis.

In conclusion, there is no superiority in chondroprotective effects for both CMI and polyurethane meniscal scaffolds compared to meniscectomy. Although meniscal scaffolds may provide improvements in clinical outcomes, no clinically relevant differences were observed when compared to meniscectomy. Additionally, there are no discernible differences between the 2 types of scaffolds.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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SUPPLEMENTARY MATERIAL

Supplementary material is available in the electronic version of this paper at the CiOS website, www.ecios.org.

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