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SYSTEMATIC REVIEW

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Suture tape augmentation in the management of anterior cruciate ligament ruptures: a systematic review and meta-analysis

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Abstract

Background The employment of suture tape augmentation (SA) in surgical interventions for anterior cruciate ligament (ACL) ruptures is a subject of ongoing debate. This meta-analysis synthesizes prior research to assess the effectiveness of additional SA in treating ACL tears.

Methods A total of four databases including PubMed, Embase, Cochrane Library, and Web of Science were searched up to September 2024. Literature screening, quality evaluation, and data extraction were performed according to inclusion and exclusion criteria. Key data extracted include: Lysholm Knee Scoring Scale, International Knee Documentation Committee Score (IKDC), self-assessment numerical evaluation (SANE), Tegner Activity Score, Knee Injury and Osteoarthritis Outcome Score (KOOS), Veterans RAND 12-Item Health Survey (VR-12), Marx Activity Scale, visual analog scale (VAS), KT-1000 anteroposterior knee laxity, and return to sports rate. Meta-analysis of outcome indicators was performed using Revman 5.4 software.

Results A total of 17 articles were included in this meta-analysis. Pre–post operation effect analysis showed that additional SA was correlated with improved IKDC, Marx Activity Scale, KOOS, VR-12 physical, and VAS for pain. In addition, there were statistically significant differences in SANE (mean difference, MD = 3.26, 95% confidence intervals, 95%CI 0.77, 5.76, $P = 0.01$, $I^2 = 13\%$) and VAS for pain (MD = −0.17, 95%CI −0.32, −0.02, $P = 0.02$, $I^2 = 0\%$) in the group using the SA technique compared with the traditional surgery group without SA. However, in terms of KT-1000 anteroposterior knee laxity, the traditional surgery group without SA was better than the group with SA (MD = 0.31, 95%CI 0.03, 0.59, $P = 0.03$, $I^2 = 0\%$).

Conclusions On the basis of current evidence, we do not believe that, compared with isolated traditional surgical methods, additional SA can significantly improve patients' functional scores and help patients heal.

Keywords Anterior cruciate ligament, Repair, Reconstruction, Suture tape augmentation

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Introduction

The anterior cruciate ligament (ACL) serves as the primary restraint against rotational instability of the knee. The management of ACL tears has garnered significant attention in recent years, with treatment primarily involving ACL reconstruction or repair [1, 2]. Frequently resulting from traumatic events during sports such as basketball, football, and skiing, ACL tears are among the most common injuries treated in orthopedic clinics [3, 4]. In addition, Zbrojkiewicz et al. [5] reported an increase in ACL tear incidence from 54.0 per 10,000 individuals annually in 2000 to 77.4 in 2015. These injuries can lead to loss of normal mobility and, eventually, secondary meniscal disease and degenerative changes [6, 7]. Although ACL reconstruction and repair remain the traditional method for restoring knee function and stability, merely 62–64% of injured individuals return to their preinjury activity levels, and 10.3% require revision surgery 10 years later [8]. Furthermore, osteoarthritis in patients is not prevented by ACL reconstruction or repair [8]. As a result, treating ACL injuries remains challenging.

Suture tape augmentation (SA) was first introduced in 1980 to increase the soft tissue grafts' tensile strength and optimize healing outcomes following ACL injuries [9]. Theoretically, its structural support could reduce retear rates and enhance knee function in the early stages, thus enhancing the patient's overall surgical result [10]. Bachmaier et al. suggested that the SA technique could reduce the possibility of graft tears, particularly for soft tissue grafts with small diameters [11]. The method has been suggested to safeguard the graft during the healing phase of the transplant, enabling earlier and safer recovery [12]. Combined with the results described by Steadman et al. [13], the SA method creates a healing environment for the ACL [14]. By shielding the ligament during the healing process and facilitating movement, this method encourages the ligament healing. Taking into account the drawbacks of the available therapies for reconstructing or repairing damaged ACL, using the SA technology to repair or reconstruct ACL has potential advantages over not using the SA technology [15]. Our hypothesis is that SA can improve patients' functional scores after ACL tear repair or reconstruction and contribute to patient healing.

Methods

This systematic review and meta-analysis were conducted in accordance with the Methodological Guidelines of the Cochrane Handbook [16] and the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) [17] (Supplementary Material S1), and they have been registered in the PROSPERO (no. CRD42023406273) website.

Search strategy

The search was conducted in four databases, Embase, PubMed, Web of Science, and Cochrane Library, up until September 2024. The specific retrieval process and details can be referred to Supplementary Material S2.

Eligibility criteria

The PICOS question served as the basis for the eligibility criteria for the systematic review and meta-analysis: P, patients with ACL tears; I, SA-assisted ACL repair or reconstruction surgery; C, Non-SA-assisted ACL repair or reconstruction; O, function score; S, randomized controlled trials (RCTs), cohort studies, and case series studies.

Inclusion criteria were: patients with (1) acute or chronic ACL tears, (2) single ACL injury with no accompanying ligament injury, (3) contact follow-up available to confirm any complications and patient-reported outcomes; no restrictions were made on the ethnicity, gender, or nationality of patients.

Exclusion criteria included: (1) multiple-ligament injury of knee joint, (2) meniscus repair, accompanied by subtotal or total meniscectomy, (3) non-English literature, (4) literature with incomplete data, and (5) patients unwilling to follow instructions or return to the clinic for follow-up.

Data extraction and quality assessment

A total of two reviewers separately extracted the data and evaluated its quality, while a third reviewer helped to reach a consensus on any differences. Information such as author, number of patients, results, average age, sex ratio, and so on were extracted. The main outcome indicators extracted in this study include: (1) the self-assessment numerical evaluation (SANE); (2) the Lysholm Knee Scoring Scale; (3) the International Knee Documentation Committee Score (IKDC); (4) the Tegner Activity Score; (5) the Veterans RAND 12-Item Health Survey (VR-12); (6) the Knee Injury and Osteoarthritis Outcome Score (KOOS); (7) the Marx Activity Scale; (8) the visual analog scale (VAS); (9) KT-1000 anteroposterior knee laxity; and (10) return-to-sports (RTS) rate. Using the Newcastle–Ottawa Scale (NOS), two reviewers independently assessed the methodological quality of the included studies, with any discrepancies being resolved through discussion with a third researcher to reach a consensus [18].

Statistical analyses

This meta-analysis consisted of two parts: changes before and after surgery in the SA group and comparison between the SA group and non-SA group. Review Manager was used for all meta-analyses, and a *P*-value of below 0.05 was deemed significant. Using Cochran's Q statistics and I^2 statistics, the degree of heterogeneity among the included studies that could not be solely ascribed to sampling error was evaluated. The interpretation of I^2 values was as follows: low (I^2: < 25%), low-to-moderate (I^2: 25–50%), moderate-to-substantial (I^2: 50–75%), or substantial (I^2: > 75%).

Results

Search results

Initially, 739 articles in total were obtained using the search strategy, 277 of which were excluded after removing duplicates, and 55 were obtained by reading the titles and abstracts in strict accordance with the inclusion and exclusion criteria. Finally, through reading the full text, 38 more studies were excluded (Supplementary Material S3) and 9 studies were included. Fig. 1 depicts the literature screening procedure.

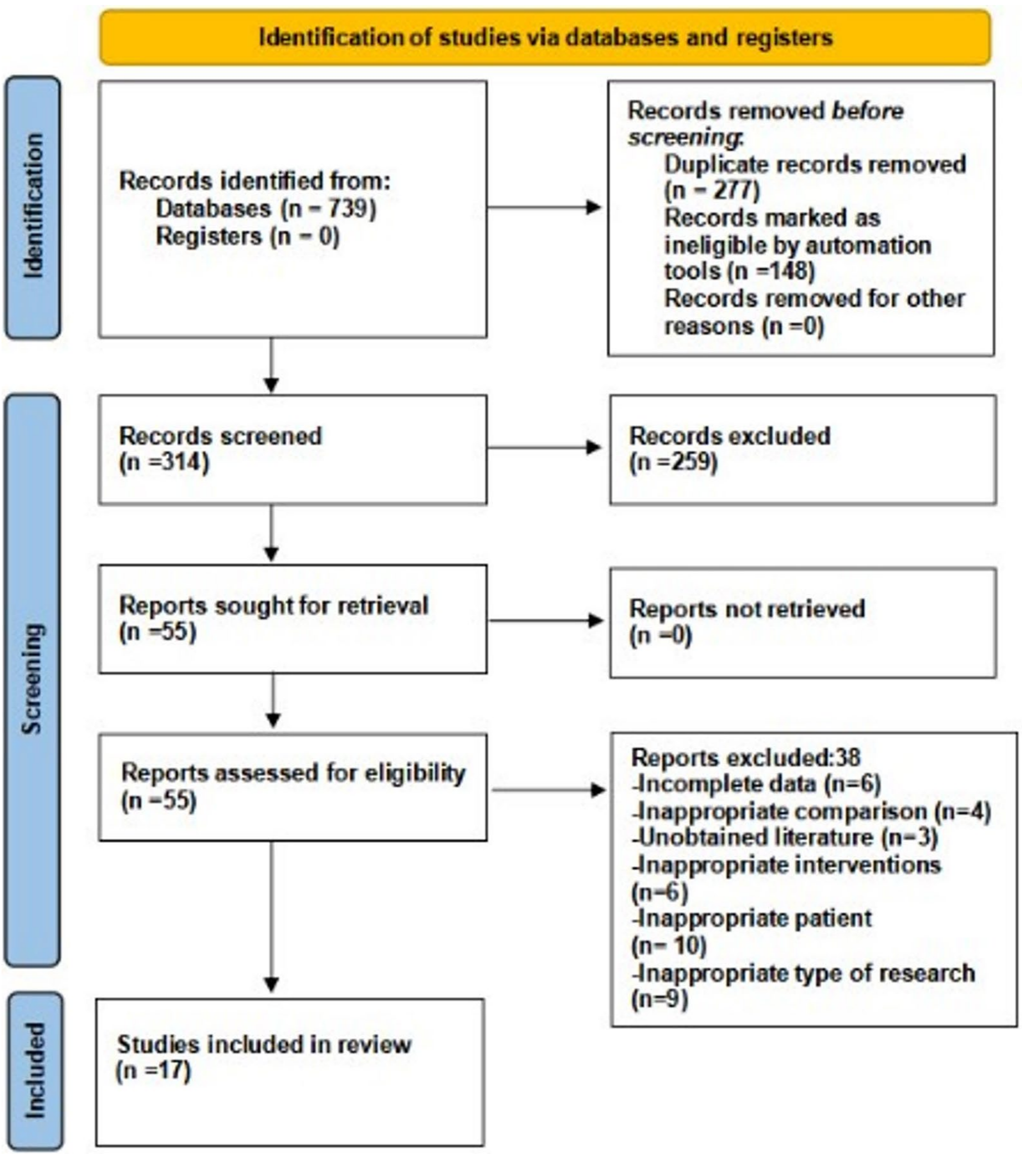

Fig. 1 The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow diagram to show study selection

Table 1 Baseline characteristics of included literature

Author	Year	Region	Suture augmented material	Sample size	BMI	Age	Sex (M/F)	Follow-up time (M)
Schneider [19]	2023	Germany	Fiber tape	77	22–27 (IQR)	33–51 (IQR)	23/57	33–44 (IQR)
Ebert [23]	2023	Australia	Fiber tape	75	24.9 ± 3.4	28.1 ± 9.2	45/30	24
Batista [24]	2023	Argentina	High resistance suture	120	24.2 ± 3.2	29.9 ± 10.5	85/35	24
Hopper [20]	2022	UK	Fiber tape	34	NA	37.8 ± 15.5	18/16	60–89
Kitchen [27]	2022	USA	Fiber tape	80	NA	9.3–18.8	37/43	27.6
Parkes [26]	2021	USA	Fiber tape	108	25.9 ± 4.7	25.3 ± 8.6	75/36	26.1
Heusdens [22]	2021	Belgium	Fiber tape	35	NA	32.8 ± 9.7	17/18	24
Heusdens [21]	2019	Belgium	Fiber tape	42	NA	33 ± 13.5	24/18	24
Bodendorfer [28]	2019	USA	Fiber tape	60	26.27 ± 3.37	29.5 ± 6.60	24/36	24
Meng [32]	2024	China	Ultra-high molecular weight polyethylene/polyester suture tape	40	25.3 ± 3.6	35.1 ± 9.9	30/10	24
Erden [31]	2021	Turkey	Ultrahigh-strength tape	63	NA	26.7 ± 4.0	36/27	≥ 24
Tensho [34]	2024	Japan	Fiber tape	106	NA	28.7 ± 14.1	45/61	≥ 24
Smith [25]	2024	USA	Fiber tape	25	25 ± 5.9	19.9 ± 6.3	9/16	≥ 24
Tavakoli darestani [33]	2023	Iran	Fiber tape	169	26.9 ± 4.5	31.0 ± 7.9	160/9	24
Daniel [30]	2023	USA	Fiber tape	200	25.8 ± 6.2	19.5 ± 5.5	98/102	≥ 24
Simard [35]	2024	Canada	Fiber tape	66	NA	37.2 ± 10.8	31/19	24
Daniel [29]	2024	USA	Fiber tape	114	26.8 ± 5.7	18.1 ± 5.7	76/55	≥ 60

NA not available, *IQR* interquartile range

Study characteristics

In all, 17 articles were incorporated into this meta-analysis, all of which were published after 2019. A total of seven case series studies [19–25], nine cohort studies [26–34], and one RCT [35] were included. Table 1 presents basic information about all the included studies. The sample size for all included studies exceeded 30 cases; 14 studies utilized fiber tape as the suture material, 1 study employed high resistance suture [24], 1 study used ultra-high molecular weight polyethylene/polyester suture tape [32], and 1 study utilized ultrahigh-strength tape [31]. Across all included studies, there were a total of 833 male and 588 female participants. The follow-up duration for all studies was equal to or greater than 2 years. A total of 4 studies focused on people younger than 23 years old [25, 27, 29, 30], while the remaining 13 studies included participants aged over 24 years. In total, ten studies provided the body mass index (BMI) range of the participants [19, 23–26, 28–30, 32, 33]. In addition, we separately summarized the conclusions of the included studies (Supplementary Material S4). All studies included in this meta-analysis had NOS scores between 8 and 9. (Supplementary Material S5).

Results of meta-analysis

Lysholm Knee Scoring Scale

In total, 5 studies involving 328 participants reported the effect of SA on Lysholm Knee Scoring Scale [26, 27, 31, 32, 34]. The analysis was done using the fixed-effects model and revealed no discernible differences within

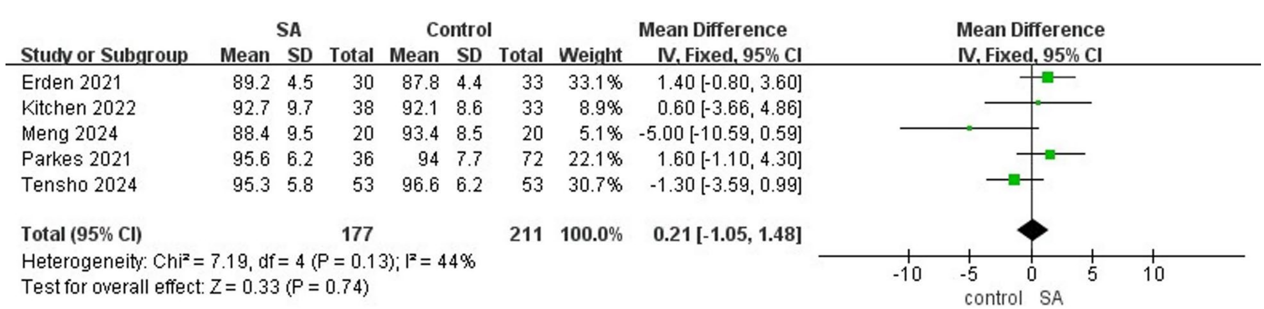

Fig. 2 Forest plots of Lysholm Knee Scoring Scale

the SA and non-SA groups (mean difference, MD = 0.21, 95% confidence intervals, 95%CI −1.05, 1.48, P = 0.74, I^2 = 44%) (Fig. 2).

IKDC

The pre–post meta-analysis contained two studies with 200 patients [23, 25]. The random-effects model was used to analyze the effects before and after operation, and the results of mete analysis demonstrated a substantial relationship between SA and the improvement of IKDC (MD = −48.31, 95%CI: −54.10, −42.51, P < 0.001, I^2 = 51%) (Supplementary Material S6). Additionally, four studies involving 377 participants reported the effect of SA on IKDC [26, 28, 32, 33]. The random-effects model was used to analyze this, and it revealed no discernible differences within the SA and non-SA groups (MD = 5.80, 95%CI −0.40, 11.99, P = 0.07, I^2 = 86%) (Fig. 3).

KOOS

The pre–post meta-analysis contained three studies with 218 patients [20, 21, 28]. The random-effects model was used to analyze the effects before and after operation, and the results of the meta-analysis demonstrated a substantial relationship between SA and the improvement of KOOS (MD = −38.31, 95%CI −46.13, −30.49, P < 0.001, I^2 = 87%) (Supplementary Material S6).

The effect of SA on VAS for pain.

The pre–post meta-analysis contained three studies with 208 patients [20, 21, 25]. The random-effects model was used to analyze the effects before and after operation, and the results of meta-analysis demonstrated a substantial relationship between SA and the improvement of VAS (MD = 1.64, 95%CI 1.06, 2.21, P < 0.001, I^2 = 70%) (Supplementary Material S6). In addition, four studies involving 447 patients reported the effect of SA on VAS for pain [27, 29, 30, 35]. A fixed-effects model was used to analyze this and revealed that VAS for pain was significantly reduced in the SA group compared with the control group (MD = −0.17, 95%CI −0.32, −0.02, P = 0.02, I^2 = 0%) (Fig. 4).

VR-12 physical

The pre–post meta-analysis contained three studies with 208 patients [20, 21, 25]. The random-effects model was used to analyze the effects before and after operation, and the results of the meta-analysis demonstrated a substantial relationship between SA and the improvement of VR-12 physical (MD = −17.49, 95%CI −22.07, −12.90, P < 0.001, I^2 = 85%) (Supplementary Material S6). In addition, two studies involving 262 patients reported the effect of SA on VR-12 physical [30, 35]. A fixed-effects model was used for analysis and no significant difference was found between the SA group and the control group (MD = −0.51, 95%CI −0.94, 1.97, P = 0.49, I^2 = 21%) (Fig. 5).

Marx activity scale

The pre–post meta-analysis contained three studies with 208 patients [20, 21, 25]. The fixed-effects model

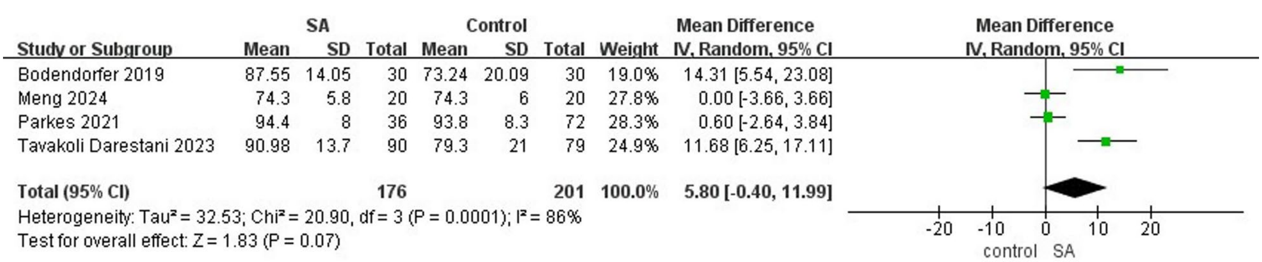

Fig. 3 Forest plots of IKDC

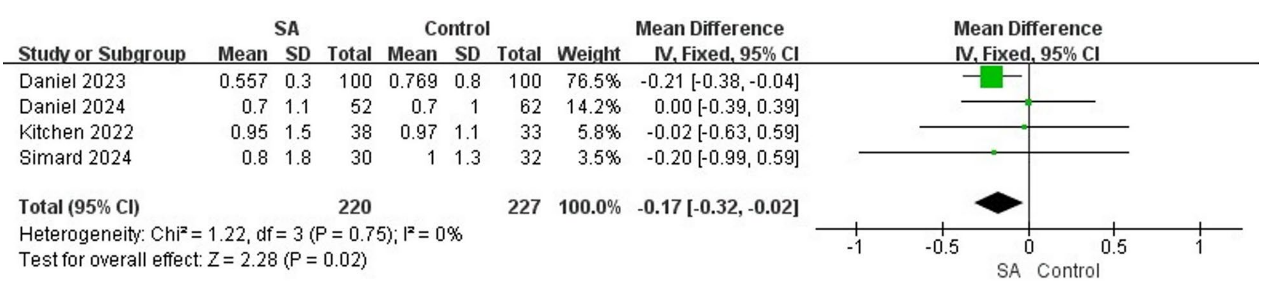

Fig. 4 Forest plots of VAS for pain

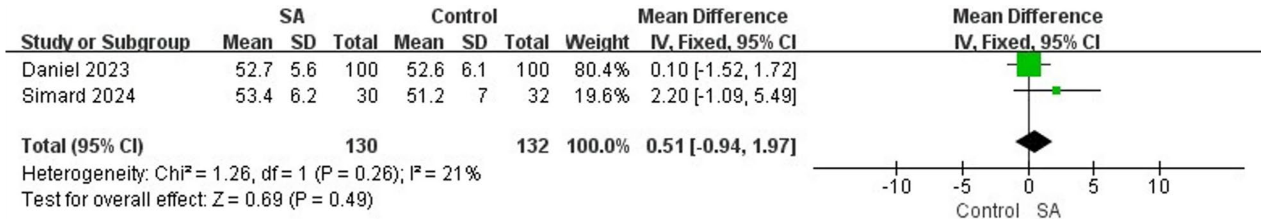

Fig. 5 Forest plots of VR-12 physical

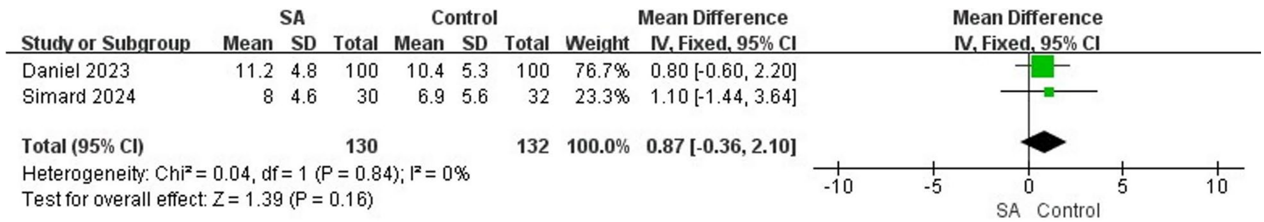

Fig. 6 Forest plots of Marx Activity Scale

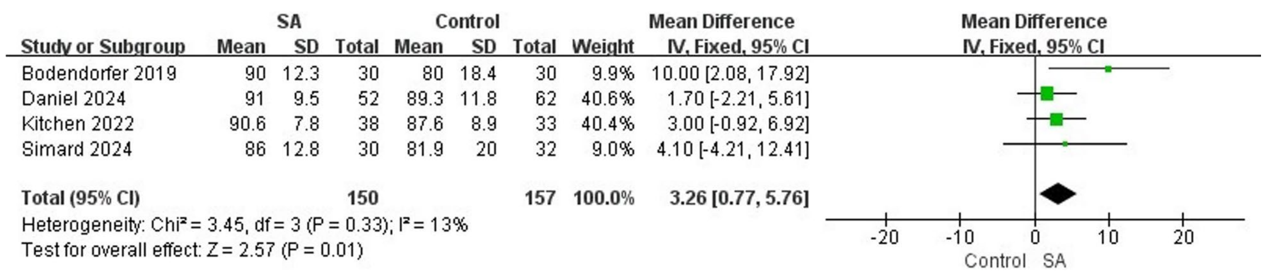

Fig. 7 Forest plots of SANE

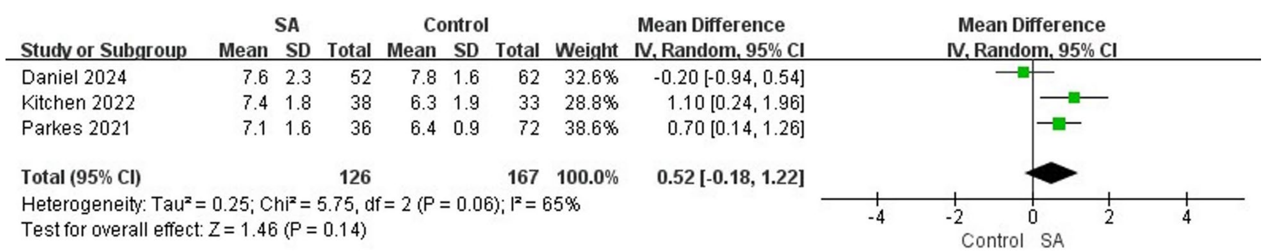

Fig. 8 Forest plots of Tegner Activity Score

was used to analyze the effects before and after operation, and the results of the meta-analysis demonstrated a substantial relationship between SA and the improvement of Marx Activity Scale (MD = 4.04, 95%CI 3.69, 4.38, $P < 0.001$, $I^2 = 0\%$) (Supplementary Material S6). In addition, two studies involving 262 patients reported the effect of SA on the Marx Activity Scale [30, 35]. A fixed-effects model was used to analyze this and revealed no significant difference between the SA group and the non-SA group (MD = 0.87, 95%CI −0.36, 2.10, $P = 0.16$, $I^2 = 0\%$) (Fig. 6).

SANE

A total of four studies involving 307 participants reported the effect of SA on SANE [26, 28]. The analysis, using a fixed-effects model, differed significantly within the SA and non-SA groups (MD = 3.26, 95%CI 0.77, 5.76, $P = 0.01$, $I^2 = 13\%$) (Fig. 7). In terms of SANE scores, the SA group performed noticeably better than the group without SA.

Tegner Activity Score

In total, three studies involving 293 participants reported the effect of SA on Tegner Activity Score [26, 27, 29]. The analysis using a random-effects model showed that there was no significant difference in Tegner Activity Score between the SA group and non-SA group (MD = 0.52, 95%CI −0.18, 1.22, $P = 0.14$, $I^2 = 65\%$) (Fig. 8).

KT-1000 anteroposterior knee laxity

A total of two studies involving 227 patients reported the effect of SA on KT-1000 anteroposterior knee laxity [29, 30]. The fixed-effects model was used to analyze this and revealed that the anteroposterior knee laxity of KT-1000 of the non-SA group was significantly better than that of the SA group (MD = 0.31, 95%CI 0.03, 0.59, $P = 0.03$, $I^2 = 0\%$) (Fig. 9).

Return-to-sports rate

A total of three studies involving 294 patients reported the effect of SA on the RTS rate [26, 27, 29]. The fixed-effects model was used to analyze this and revealed that there was no significant difference between the SA group and the non-SA group in improving the RTS rate (MD = 1.07, 95%CI 0.96, 1.19, $P = 0.22$, $I^2 = 16\%$) (Fig. 10).

Discussion

ACL tears are common knee injuries, particularly prevalent in young patients, and can seriously affect patients' quality of life [36]. SA is a simple, rapid technique that provides additional stability to the ACL [37]. Our meta-analysis of 17 studies demonstrated that, in the SA group, the postoperative numerical evaluation of Marx Activity Scale, IKDC, KOOS, VR-12 physical, and VAS for pain significantly improved compared with the preoperative evaluation. In addition, the SA group achieved superior outcomes in the SANE score and VAS for pain relative to the non-SA group, while the non-SA group displayed better KT-1000 anteroposterior knee laxity. No statistically significant differences were observed between groups in Lysholm Knee Scoring Scale, IKDC score, VR-12 physical, Marx Activity Scale, Tegner Activity Score, or RTS rate.

The ACL is an intraarticular ligament enveloped by synovial tissue that supplies the ligament with blood flow [38]. The use of the SA technique, based on surgery for ACL tears, serves to biomechanically reinforce the ACL and promote early activity and safeguard the ligament throughout the healing process to enhance the natural recovery process [10]. These mechanisms may explain the significant improvement of Marx Activity Scale, IKDC, KOOS, VR-12 physical, and VAS for pain after surgery compared with that before surgery—a key finding of this study. Another important finding was that additional SA was not superior to isolated traditional surgical methods (e.g., ACL repair or

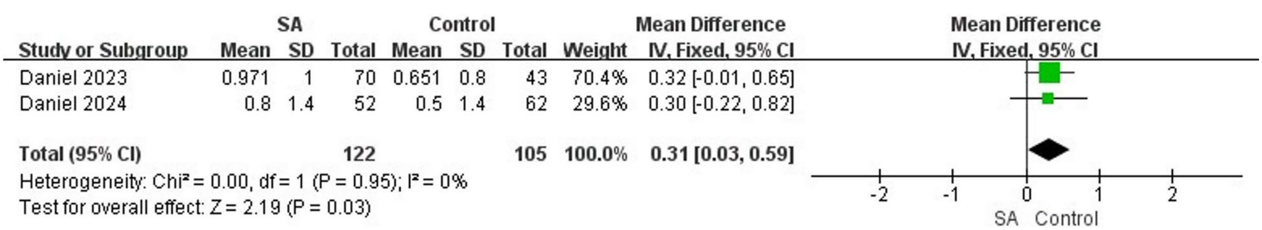

Fig. 9 Forest plots of KT-1000 anteroposterior knee laxity

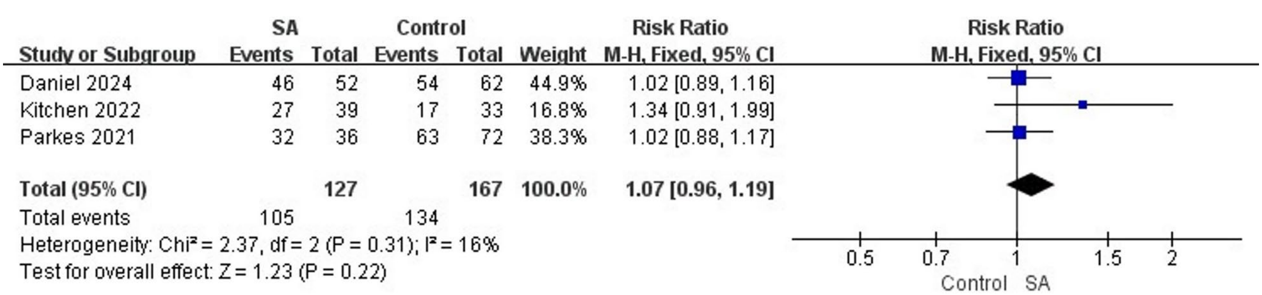

Fig. 10 Forest plots of return-to-sports rate

reconstruction). Stress-shielding may be one underlying reason, which may have a negative effect on graft ligamentization and graft bone interface healing [32]. Another reason may be the small number of randomized controlled studies and the surgeon's subjective selection of surgical methods. After all, surgeons are more likely to use SA for patients with a higher graft failure rate. The heterogeneity in our meta-analysis may stem from: (1) variability in ACL injury patterns and (2) age-related differences in tear incidence, with older age correlating strongly with ACL injury risk [39].

Similar to our findings, a systematic review of five studies by Dhillon et al. found insufficient evidence to suggest that patients undergoing anterior cruciate ligament reconstruction (ACLR) combined with SA had better clinical outcomes compared with isolated ACLR [40]. According to systematic review by Zhang et al., patients using ACLR with SA tended to have a higher RTS rate; however, it was not statistically significant. Furthermore, compared with ACLR alone, ACLR with SA is no better in most functional scores, knee stability measures and graft failure rates [41]. Conversely, an analysis of nine studies by Wilson et al. showed satisfactory subjective scores and clinical laxity testing results and concluded that ACL repair with internal bracing is a safe technique for the treatment of proximal fractures [42]. However, this conclusion should be interpreted cautiously, as the review predominantly included low-quality case series with high bias risks. A case series study published by Wilson et al. showed a 1.1% failure rate at 5-year follow-up, which is lower than the published rate. However, the age and activity levels of the cohort may account for the low refracture rate, and a small number of high-risk patients were initially excluded; therefore, its applicability is limited [43]. A biomechanical study has shown that ACL repair with SA can restore knee laxity closer to that of an intact ACL; however, more clinical trials are still needed to prove this [44].

The following limitations remain in this study and need further improvement and refinement. First, the included studies' follow-up durations differed, which may affect the outcome of the data measurement. Second, the sample size of some studies is relatively small. We suggest that future research should prioritize the following aspects: first, increase the sample size of studies to reduce bias. Second, it should focus on standardizing and extending the follow-up time. Third, researchers are advised to conduct more randomized controlled trials. Fourth, the clinical characteristics of the subjects should be fully described at the time of trial design and implementation to improve the comparability of the experimental and control groups.

Conclusions

On the basis of current evidence, we do not believe that, compared with isolated traditional surgical methods, additional SA can significantly improve patients' functional scores and help patients heal.

Abbreviations

SA	Suture tape augmentation
ACL	Anterior cruciate ligament
RCT	Randomized controlled trial
SANE	Self-assessment numerical evaluation
IKDC	International Knee Documentation Committee Score
VR-12	Veterans RAND 12-Item Health Survey
KOOS	Knee Injury and Osteoarthritis Outcome Score
VAS	Visual analog scale
RTS	Return to sports
BMI	Body mass index
ACLR	Anterior cruciate ligament reconstruction

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s10195-025-00845-y.

Supplementary material 1.

Supplementary material 2.

Supplementary material 3.

Supplementary material 4.

Supplementary material 5.

Supplementary material 6.

Acknowledgements

Not applicable.

Author contributions

Peiyuan Tang, Yangbin Cao, and Yusheng Li developed the idea, designed the study, had full access to all data in the study, take responsibility for the integrity of the data and the accuracy of the data analysis. Peiyuan Tang, Yangbin Cao, Wenfeng Xiao, and Ting Wen ran the search strategy; Yangbin Cao and Peiyuan Tang selected articles and extracted data. Peiyuan Tang evaluated the quality of the literature. Peiyuan Tang, Yangbin Cao, Wenfeng Xiao, Ting Wen, Jun Zhang, Yusheng Li, Shuguang Liu, Ying Zhu, Han Tan, and Haoxuan Li wrote the manuscript. All listed authors reviewed and approved the final manuscript.

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Data availability

The data that support the findings of this study are available on request from the corresponding author upon reasonable request and with the provision of a data sharing agreement.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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