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Original Article

Effect of irrigation fluid temperature on postoperative swelling, pain, and long-term functional recovery following arthroscopic rotator cuff repair

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Abstract: Objective: To evaluate the effects of irrigation fluid temperature on postoperative swelling, pain, complications, and functional recovery in patients undergoing arthroscopic rotator cuff repair. Methods: This retrospective study analyzed clinical data from 410 patients who underwent arthroscopic rotator cuff repair at Putuo Hospital between April 2020 and November 2024. Patients were divided into two groups according to irrigation fluid temperature: isothermic (37 °C, n = 178) and room temperature (22-24 °C, n = 232). Propensity score matching (PSM) was applied to balance baseline characteristics, yielding 164 patients per group. Primary outcomes included shoulder circumference at 7 and 14 days postoperatively, Visual Analog Scale (VAS) scores at 2, 12, and 24 hours postoperatively, incidence of postoperative hypothermia and shivering, and University of California, Los Angeles (UCLA; ≥ 26) and American Shoulder and Elbow Surgeons (ASES; ≥ 85) scores at 6 months. Logistic regression was used to compare outcomes between groups and identify prognostic factors. Results: After PSM, the isothermic group had significantly smaller shoulder circumference at both 7 and 14 days postoperatively compared with the room temperature group (both $P < 0.001$). VAS scores at 12 hours postoperatively were also significantly lower in the isothermic group ($P < 0.001$). No significant between-group differences were found in postoperative hypothermia ($P = 0.077$) or shivering ($P = 0.448$). UCLA and ASES scores at 3 and 6 months showed no significant differences (all $P > 0.05$). Multivariate logistic regression identified body mass index (BMI) as an independent prognostic factor (OR = 0.592, 95% CI: 0.354-0.978, $P = 0.043$). Conclusions: Isothermic irrigation fluid significantly reduces early postoperative swelling and pain but does not appear to influence long-term functional recovery. Its effect on postoperative hypothermia and shivering is minimal. BMI was identified as an independent prognostic factor.

Keywords: Arthroscopic rotator cuff repair, irrigation fluid temperature, postoperative swelling, postoperativepain, functional recovery, hypothermia

Introduction

Rotator cuff tears are a common cause of shoulder pain and functional limitation in clinical practice. Arthroscopic rotator cuff repair is widely regarded as the surgical gold standard due to its minimally invasive approach and proven clinical efficacy [1]. In this procedure, continuous irrigation is essential for maintaining clear visualization and stable intra-articular pressure [2], underscoring its critical role in surgical success. Despite this, irrigation fluid is typically used at room temperature in standard surgical protocols, and the physiological implications of this practice form the rationale for our investigation [3].

Prolonged exposure to high volumes of room-temperature irrigation fluid poses both local and systemic challenges. Locally, direct contact of fluid below core body temperature with the joint capsule, synovium, and cartilage may induce vasoconstriction and alter microcirculatory perfusion. These changes can exacerbate postoperative inflammatory responses, potentially contributing to increased joint swelling and pain [4]. Systemically, continuous heat loss from irrigation can disrupt thermoregula-

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tory homeostasis, increasing the risk of perioperative hypothermia and shivering [5]. Such complications not only impair patient comfort but may also trigger cardiovascular stress responses, thereby delaying recovery.

The use of isothermic irrigation fluid, maintained near physiologic temperature, has been proposed as a strategy to mitigate these risks. While theoretical benefits include improved patient comfort and reduced shivering, clinical evidence remains inconclusive. Some studies have reported favorable outcomes, whereas others have found no consistent effects on postoperative swelling, pain control, or long-term functional recovery [6, 7].

We hypothesize that a key reason for these inconsistent findings was inadequate control of confounding variables in previous research. Patient baseline characteristics - such as age, body mass index (BMI), disease duration, and osteoporotic status - are known predictors of postoperative recovery.

The primary research question of this study was: after controlling for major confounding factors, does irrigation fluid temperature independently influence postoperative outcome in patients undergoing arthroscopic rotator cuff repair? To address this, we conducted a large-sample retrospective cohort study, systematically comparing two irrigation temperature protocols. Outcomes assessed included early postoperative swelling (1-14 days), dynamic pain at 2, 12, and 24 hours, perioperative hypothermia and shivering, and long-term functional recovery at 3 and 6 months.

Patients and methods

Sample collection

A retrospective analysis was performed on patients undergoing arthroscopic rotator cuff repair at Putuo Hospital between April 2020 and November 2024 (n = 410). Patients were categorized according to intraoperative irrigation temperature: isothermic group (37°C, n = 178) and room temperature group (22-24°C, n = 232). The study protocol was approved by the Putuo Hospital Medical Ethics Committee.

Inclusion and exclusion criteria

Inclusion criteria: 1. Age 18-80 years; 2. Radiologically confirmed rotator cuff tear (MRI or CT) [2]; 3. Arthroscopic rotator cuff repair with defined irrigation temperature (isothermic 37°C; room temperature 22-24°C); 4. Complete pre-, intra-, and postoperative follow-up data available.

Exclusion criteria: 1. Coexisting shoulder pathology (dislocation, fracture, severe arthritis); 2. Severe systemic disease (malignancy, severe cardiopulmonary insufficiency, uncontrolled diabetes); 3. Previous ipsilateral shoulder surgery (rotator cuff repair or joint replacement); 4. Anti-inflammatory or analgesic drug use within 4 weeks; 5. Hematological disorders.

Sample size calculation

Sample size was determined using the *TrialSize* package in R (Two Sample Proportion function). Based on published data [8], the incidence of intraoperative shivering was 21.2% with room temperature irrigation (20-22°C) and 2.9% with isothermic irrigation (36-37°C). With a two-sided $\alpha = 0.05$, 90% power, and a 1:1 allocation ratio, 62 patients per group were required. Allowing for a 15% loss to follow-up, the final target sample size was 146 patients (73 per group) to detect a significant difference in shivering incidence.

Surgical protocol

All surgeries were performed by a single surgical team in laminar flow operating rooms following standardized protocols. Preoperative evaluation ensured no surgical contraindications. Procedures were conducted under general anesthesia combined with brachial plexus block. Patients were positioned laterally with the affected shoulder abducted 45° and flexed forward 15°, secured to a traction apparatus.

A standard arthroscopic system (Stryker, 4.0 mm, 30° arthroscope) was used with posterior, lateral, and anterior portals. Continuous irrigation maintained intra-articular pressure (50-60 mmHg), with fluid temperature determined by group assignment. The isothermic group received 37°C ± 0.5°C normal saline (3 L/bag)

through a thermostat-controlled system; the room temperature group received 22-24°C normal saline (3 L/bag) stored at ambient temperature. Flow rates were maintained at 100-150 mL/min, adjusted as needed for visualization.

Surgery began with diagnostic arthroscopy to assess tear size, location, retraction, and concomitant injuries. Debridement, adhesion release, and preparation of the tear edges were performed. Full-thickness tears were repaired with single- or double-row nonabsorbable anchor fixation (Smith & Nephew, 4.5 mm) using high-strength polyethylene sutures (#2 Ethibond). Partial tears were managed with *in-situ* repair or conversion to full-thickness repair based on intraoperative findings. Post-repair, range of motion and fixation stability were confirmed, joint lavage performed, and wounds closed with layered sutures and compression dressing.

Postoperative management

Postoperative care included intermittent ice application (15 min/session every 2 h for 24 h), shoulder immobilization for 4-6 weeks, and prophylactic antibiotics (cefuroxime sodium 1.5 g IV for 24 h). Pain was managed with oral ibuprofen 400 mg every 8 h as needed. Passive range-of-motion exercises began on postoperative day 1, progressing to active motion at 4 weeks and intensive rehabilitation at 8 weeks.

Clinical data collection

Data were extracted from electronic medical records and follow-up documentation, including demographics (age, sex, BMI, smoking, alcohol use, diabetes, hypertension), disease characteristics (pain duration, location, osteoporosis, tear length), and surgical details (protocol, operative time, blood loss). Postoperative outcomes included shoulder circumference, Visual Analog Scale (VAS) scores, hypothermia/shivering incidence, University of California Los Angeles Shoulder Score (UCLA score), American Shoulder and Elbow Surgeons Score (ASES score), and prognosis.

Functional scoring

The UCLA score [9] assessed pain, function, active range of motion, strength, and satisfaction (0-35; ≥ 26 at 6 months = favorable prognosis). The ASES score [10] evaluated pain and daily activities (0-100; ≥ 85 at 6 months = favorable prognosis). The VAS [11] assessed pain severity (0-10; higher scores = more severe pain).

Outcome measures

Primary outcomes: Postoperative swelling and changes in functional scores [9]. Prognosis was defined using UCLA ≥ 26 and ASES ≥ 85 at 6 months, based on Moorthy [12] and Patel [13].

Secondary outcomes: Changes in VAS scores and incidence of hypothermia/shivering [11]. Propensity score matching (PSM) with a caliper of 0.2 was used to balance baseline variables. Post-matching differences in outcomes and adverse prognostic factors were analyzed.

Statistical analysis

Data were analyzed using R (v4.3.3). Categorical variables expressed as counts and percentages, were compared using chi-square tests (standard, continuity-corrected, or Fisher's exact as appropriate). Continuous variables were tested for normality (Kolmogorov-Smirnov test); normally distributed data were compared using t-tests (mean ± SD), and non-normally distributed data using Mann-Whitney U or Wilcoxon signed-rank tests (median, IQR). Prognostic factors were identified using univariate and multivariate logistic regression, reporting ORs, 95% CIs, and *P*-values. Covariate balance before and after PSM was assessed via standardized mean differences. Results were visualized with forest plots (*forestplot* package) and Venn diagrams (*VennDiagram* package). Significance was set at $\alpha = 0.05$ (two-sided).

Primary R packages included: *dplyr, stats, MatchIt, optmatch, cobalt, forestplot, VennDiagram, ggplot2, gridExtra*, and *broom*.

Results

Comparison of baseline characteristics

No statistically significant differences were observed between groups in gender distribution, prevalence of diabetes, prevalence of hypertension, smoking history, alcohol consumption history, shoulder pain location, osteoporosis prevalence, rotator cuff tear length, operative time, or intraoperative blood loss (all $P > 0.05$).

Table 1. Comparison of baseline characteristics [n (%)]

Factor	Total	Room Temperature Group (n = 232)	Isothermic Group (n = 178)	Test Statistic	*P*-value
Age					
≥ 60 years	256 (62.44%)	158 (68.10%)	98 (55.06%)	7.311	0.007
< 60 years	154 (37.56%)	74 (31.90%)	80 (44.94%)		
Gender					
Male	229 (55.85%)	128 (55.17%)	101 (56.74%)	0.101	0.751
Female	181 (44.15%)	104 (44.83%)	77 (43.26%)		
BMI					
≥ 24	131 (31.95%)	86 (37.07%)	45 (25.28%)	6.437	0.011
< 24	279 (68.05%)	146 (62.93%)	133 (74.72%)		
Diabetes					
Yes	65 (15.85%)	35 (15.09%)	30 (16.85%)	0.236	0.627
No	345 (84.15%)	197 (84.91%)	148 (83.15%)		
Hypertension					
Yes	85 (20.73%)	46 (19.83%)	39 (21.91%)	0.266	0.606
No	325 (79.27%)	186 (80.17%)	139 (78.09%)		
Smoking History					
Yes	228 (55.61%)	125 (53.88%)	103 (57.87%)	0.648	0.421
No	182 (44.39%)	107 (46.12%)	75 (42.13%)		
Alcohol History					
Yes	95 (23.17%)	51 (21.98%)	44 (24.72%)	0.424	0.515
No	315 (76.83%)	181 (78.02%)	134 (75.28%)		
Shoulder Pain Duration					
≥ 6 months	237 (57.80%)	146 (62.93%)	91 (51.12%)	5.757	0.016
< 6 months	173 (42.20%)	86 (37.07%)	87 (48.88%)		
Shoulder Pain Location					
Left	233 (56.83%)	128 (55.17%)	105 (58.99%)	0.598	0.439
Right	177 (43.17%)	104 (44.83%)	73 (41.01%)		
Osteoporosis					
Yes	56 (13.66%)	35 (15.09%)	21 (11.80%)	0.924	0.337
No	354 (86.34%)	197 (84.91%)	157 (88.20%)		
Rotator Cuff Tear Length					
≥ 2 cm	212 (51.71%)	118 (50.86%)	94 (52.81%)	0.153	0.696
< 2 cm	198 (48.29%)	114 (49.14%)	84 (47.19%)		
Operative Time					
≥ 60 min	261 (63.66%)	142 (61.21%)	119 (66.85%)	1.388	0.239
< 60 min	149 (36.34%)	90 (38.79%)	59 (33.15%)		
Intraoperative Blood Loss					
≥ 60 mL	186 (45.37%)	111 (47.84%)	75 (42.13%)	1.325	0.25
< 60 mL	224 (54.63%)	121 (52.16%)	103 (57.87%)		

Note: BMI, Body Mass Index.

However, significant differences were found in age distribution (P = 0.007), with the room temperature group having a higher proportion of patients aged ≥ 60 years. BMI distribution also differed significantly (P = 0.011), with the room temperature group showing a higher proportion of patients with BMI ≥ 24 kg/m^2. Shoulder pain duration was significantly longer in the room temperature group (P = 0.016), which had a greater proportion of patients with pain duration ≥ 6 months (**Table 1**).

Table 2. Comparison of postoperative joint swelling

Variable	Room Temperature Group (n = 232)	Isothermic Group (n = 178)	Test Statistic	*P*-value
Preoperative circumference	45.22 ± 2.17	45.55 ± 2.83	1.779	0.075
Postoperative day 1 circumference	50.04 ± 2.98*	49.94 ± 2.44*	0.729	0.466
Postoperative day 7 circumference	49.01 ± 3.57*,#	46.29 ± 2.69*,#	7.809	< 0.001
Postoperative day 14 circumference	47.58 ± 2.72*,#,&	45.70 ± 2.06#	7.650	< 0.001

Note: * indicates P < 0.05 compared to preoperative; # indicates P < 0.05 compared to postoperative day 1; & indicates P < 0.05 compared to postoperative day 7.

Table 3. Comparison of postoperative pain score [Median (Interquartile Range)]

Variable	Room Temperature Group (n = 232)	Isothermic Group (n = 178)	Test Statistic	*P*-value
Preoperative VAS	6.94 ± 1.59	7.09 ± 1.42	0.863	0.388
Postoperative 2 h VAS	1.95 ± 0.96*	2.07 ± 1.06*	1.591	0.112
Postoperative 12 h VAS	5.56 ± 1.30*,#	4.03 ± 1.06*,#	11.098	< 0.001
Postoperative 24 h VAS	3.60 ± 0.90*,#,&	3.45 ± 1.08*,#,&	1.175	0.24

Note: * indicates P < 0.05 compared to preoperative; # indicates P < 0.05 compared to postoperative 2 h; & indicates P < 0.05 compared to postoperative 12 h; VAS, Visual Analog Scale.

Comparison of postoperative joint swelling

There were no significant differences between groups in preoperative shoulder circumference or in circumference on postoperative day 1 (all P > 0.05). At postoperative days 7 and 14, the isothermic group had significantly smaller shoulder circumference compared with the room temperature group (both P < 0.001).

Within-group analysis showed that shoulder circumference increased significantly at postoperative days 1, 7, and 14 compared with preoperative values (all P < 0.05). Circumference decreased significantly from day 1 to days 7 and 14 in both groups (all P < 0.05). In the room temperature group, circumference further decreased from day 7 to day 14 (P < 0.05), whereas no significant change was observed between days 7 and 14 in the isothermic group (P > 0.05) (**Table 2**).

Comparison of postoperative pain scores

Preoperative, 2-hour, and 24-hour postoperative VAS scores did not differ significantly between groups (all P > 0.05). At 12 hours postoperatively, the isothermic group reported significantly lower VAS scores than the room temperature group (P < 0.001).

In both groups, VAS scores at 2, 12, and 24 hours were significantly lower than preoperative scores (all P < 0.05). Pain scores increased significantly from 2 to 12 hours and from 2 to 24 hours (P < 0.05), followed by a significant decrease from 12 to 24 hours (P < 0.05) (**Table 3**).

Comparison of postoperative hypothermia and shivering incidence

The incidence of postoperative hypothermia was significantly lower in the isothermic group compared with the room temperature group (P = 0.030). However, no significant between-group difference was observed in the incidence of postoperative shivering (P = 0.474) (**Table 4**).

Comparison of postoperative functional recovery scores

There were no significant differences between groups in preoperative, 3-month, or 6-month UCLA scores (all P > 0.05) and no significant differences in preoperative, 3-month, or 6-month ASES scores (all P > 0.05).

Both groups showed significant improvement in UCLA scores at 3 and 6 months compared to preoperative values (P < 0.05), with further improvement from 3 to 6 months (P < 0.05). Similarly, both groups demonstrated significant improvement in ASES scores at 3 and 6 months compared to preoperative values (P <

Table 4. Comparison of postoperative hypothermia and shivering [n (%)]

Factor	Total	Room Temperature Group (n = 232)	Isothermic Group (n = 178)	Test Statistic	*P*-value
Postoperative Hypothermia					
Yes	29 (7.07%)	22 (9.48%)	7 (3.93%)	4.720	0.03
No	381 (92.93%)	210 (90.52%)	171 (96.07%)		
Postoperative Shivering					
Yes	8 (1.95%)	6 (2.59%)	2 (1.12%)	-	0.474
No	402 (98.05%)	226 (97.41%)	176 (98.87%)		

Table 5. Comparison of postoperative UCLA and ASES scores [Median (Interquartile Range) or Mean ± Standard Deviation]

Variable	Room Temperature Group (n = 232)	Isothermic Group (n = 178)	Test Statistic	*P*-value
UCLA				
Preoperative	15.37 ± 2.40	15.51 ± 2.55	0.798	0.425
3 months postoperative	21.27 ± 2.30*	21.16 ± 2.39*	0.706	0.48
6 months postoperative	28.61 ± 3.43*,#	28.54 ± 3.50*,#	0.241	0.81
ASES				
Preoperative	55.54 ± 4.67	54.98 ± 4.01	1.208	0.227
3 months postoperative	75.99 ± 5.23*	75.96 ± 5.03*	-0.071	0.944
6 months postoperative	85.51 ± 5.14*,#	85.70 ± 5.26*,#	0.283	0.777

Note: * indicates P < 0.05 compared to preoperative; # indicates P < 0.05 compared to 3 months postoperative. UCLA, University of California, Los Angeles Shoulder Score; ASES, American Shoulder and Elbow Surgeons Score.

0.05), with further improvement from 3 to 6 months (P < 0.05) (**Table 5**).

Comparison of prognostic outcomes

Based on postoperative 6-month UCLA score (≥ 26) and ASES score (≥ 85) thresholds, 190 of 410 patients achieved favorable prognosis, while 220 had unfavorable outcomes. **Figure 1** illustrates patient distribution according to both scoring criteria, showing that 31 patients (7.6%) failed to meet either threshold. Baseline data comparisons between prognosis groups are provided in Table S1.

Logistic regression analysis for independent risk factors affecting patient prognosis

Univariate logistic regression identified age (OR = 2.399, 95% CI: 1.583-3.637, P < 0.001), BMI (OR = 2.299, 95% CI: 1.504-3.514, P < 0.001), shoulder pain duration (OR = 1.779, 95% CI: 1.194-2.651, P = 0.005), osteoporosis (OR = 2.558, 95% CI: 1.416-4.623, P = 0.002), and rotator cuff tear length (OR = 1.944, 95% CI: 1.311-2.884, P < 0.001) as significant predictors of poor prognosis. Gender showed marginal significance (OR = 1.484, 95% CI: 1.001-2.200, P = 0.049).

Treatment protocol, diabetes, hypertension, smoking, alcohol consumption, pain location, operative time, intraoperative blood loss, postoperative hypothermia, and postoperative shivering were not significantly associated with prognosis (all P > 0.05) (**Figure 2**).

Multivariate logistic regression confirmed age (OR = 2.129, 95% CI: 1.380-3.311, P < 0.001), BMI (OR = 1.930, 95% CI: 1.231-3.041, P = 0.004), shoulder pain duration (OR = 1.610, 95% CI: 1.052-2.474, P = 0.029), osteoporosis (OR = 2.348, 95% CI: 1.264-4.479, P = 0.008), and rotator cuff tear length (OR = 1.975, 95% CI: 1.304-3.008, P = 0.001) as independent prognostic factors. Gender was not significant in the multivariate model (P = 0.061) (**Figure 2**).

Comparison of covariate balance before and after PSM

Before matching, significant differences were observed in age, BMI, and pain duration between groups (all P < 0.05). After PSM, stan-

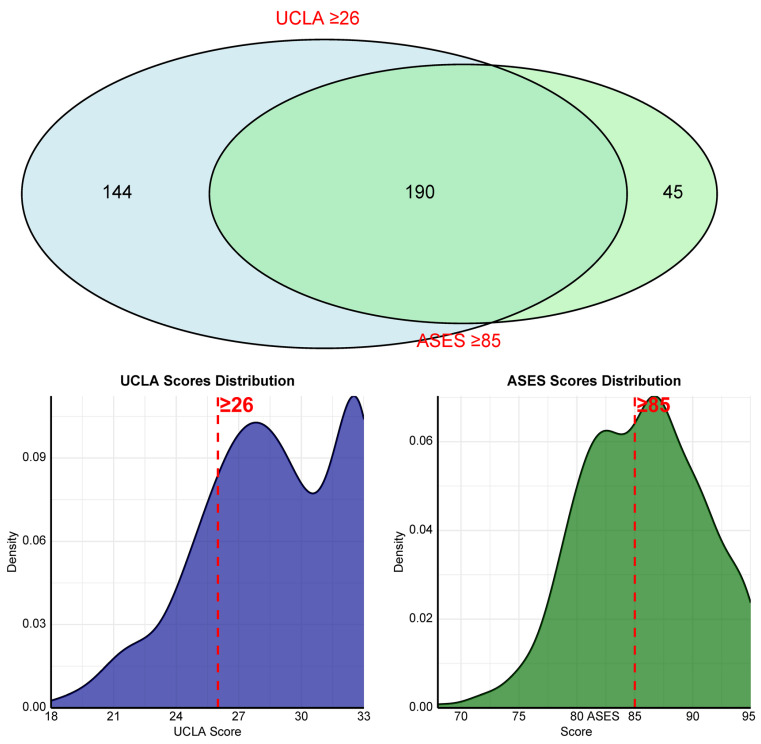


Figure 1. Patient distribution based on UCLA and ASES score thresholds and score distributions. Note: The figure illustrates the distribution of patients meeting the score thresholds, with 31 patients (7.6%) failing to meet both criteria. UCLA, University of California, Los Angeles Shoulder Score; ASES, American Shoulder and Elbow Surgeons Score.

dardized mean differences were substantially reduced, and no significant differences remained (all P > 0.05), indicating successful baseline balance (**Figure 3**).

Comparison of baseline characteristics after PSM

Following matching, there were no significant inter-group differences in age, BMI, pain duration, or hypertension (P = 1.000). Gender, diabetes, smoking, alcohol consumption, pain location, osteoporosis, tear length, operative time, and intraoperative blood loss also showed no significant differences (all P > 0.05) (**Table 6**).

Comparison of postoperative joint swelling after PSM

After matching, no significant differences were observed in preoperative and postoperative day 1 shoulder circumference (P > 0.05). At days 7 and 14, the isothermic group had significantly smaller circumference than the room temperature group (both P < 0.001).

In both groups, circumference increased significantly at days 1, 7, and 14 compared with preoperative values (all P < 0.05) and decreased significantly at days 7 and 14 compared with day 1 (both P < 0.05). In the room temperature group, circumference further decreased from day 7 to day 14 (P < 0.05), whereas no significant change was observed between these two time points in the isothermic group (P > 0.05) (**Table 7**).

Comparison of postoperative pain scores after PSM

Post-PSM, there were no significant differences in preoperative, 2-hour, and 24-hour VAS scores between groups (all P > 0.05). At 12 hours, the isothermic group reported significantly lower VAS scores than the room temperature group (P < 0.001).

Within both groups, VAS scores at 2, 12, and 24 hours were significantly lower than preoperative scores (P < 0.05). Pain scores increased significantly from 2 to 12 hours and from 2 to 24 hours (P < 0.05) before decreasing significantly from 12 to 24 hours (P < 0.05) (**Table 8**).

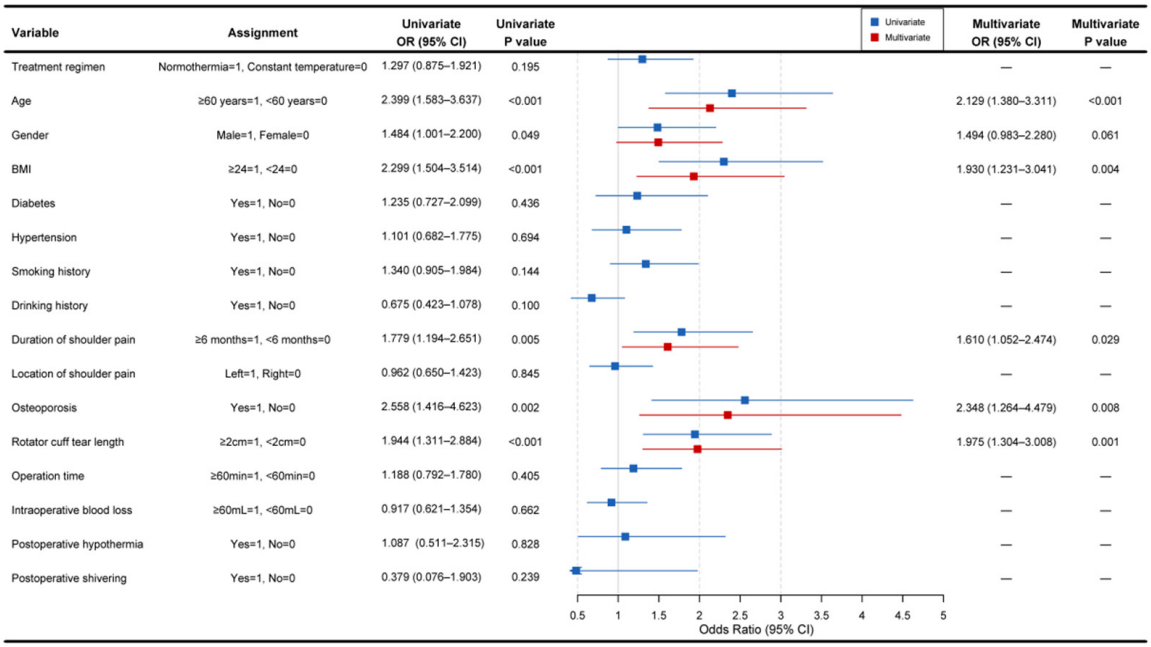
Comparison of postoperative hypothermia and shivering after PSM

After matching, the incidence of postoperative hypothermia did not differ significantly between the isothermic and room temperature groups (P = 0.077). Postoperative shivering incidence was also comparable (P = 0.448) (**Table 9**).

Comparison of functional recovery scores after PSM

No significant differences were found between groups in preoperative, 3-month, and 6-month UCLA scores, or in preoperative, 3-month, and 6-month ASES scores (all P > 0.05).

Both groups showed significant improvements in UCLA and ASES scores at 3 and 6 months



Variable	Assignment	Univariate OR (95% CI)	Univariate P value	Multivariate OR (95% CI)	Multivariate P value
Treatment regimen	Normothermia=1, Constant temperature=0	1.297 (0.875–1.921)	0.195	—	—
Age	≥60 years=1, <60 years=0	2.399 (1.583–3.637)	<0.001	2.129 (1.380–3.311)	<0.001
Gender	Male=1, Female=0	1.484 (1.001–2.200)	0.049	1.494 (0.983–2.280)	0.061
BMI	≥24=1, <24=0	2.299 (1.504–3.514)	<0.001	1.930 (1.231–3.041)	0.004
Diabetes	Yes=1, No=0	1.235 (0.727–2.099)	0.436	—	—
Hypertension	Yes=1, No=0	1.101 (0.682–1.775)	0.694	—	—
Smoking history	Yes=1, No=0	1.340 (0.905–1.984)	0.144	—	—
Drinking history	Yes=1, No=0	0.675 (0.423–1.078)	0.100	—	—
Duration of shoulder pain	≥6 months=1, <6 months=0	1.779 (1.194–2.651)	0.005	1.610 (1.052–2.474)	0.029
Location of shoulder pain	Left=1, Right=0	0.962 (0.650–1.423)	0.845	—	—
Osteoporosis	Yes=1, No=0	2.558 (1.416–4.623)	0.002	2.348 (1.264–4.479)	0.008
Rotator cuff tear length	≥2cm=1, <2cm=0	1.944 (1.311–2.884)	<0.001	1.975 (1.304–3.008)	0.001
Operation time	≥60min=1, <60min=0	1.188 (0.792–1.780)	0.405	—	—
Intraoperative blood loss	≥60mL=1, <60mL=0	0.917 (0.621–1.354)	0.662	—	—
Postoperative hypothermia	Yes=1, No=0	1.087 (0.511–2.315)	0.828	—	—
Postoperative shivering	Yes=1, No=0	0.379 (0.076–1.903)	0.239	—	—

Figure 2. Independent risk factor screening results for patient prognosis. Note: OR, Odds Ratio; CI, Confidence Interval; BMI, Body Mass Index.

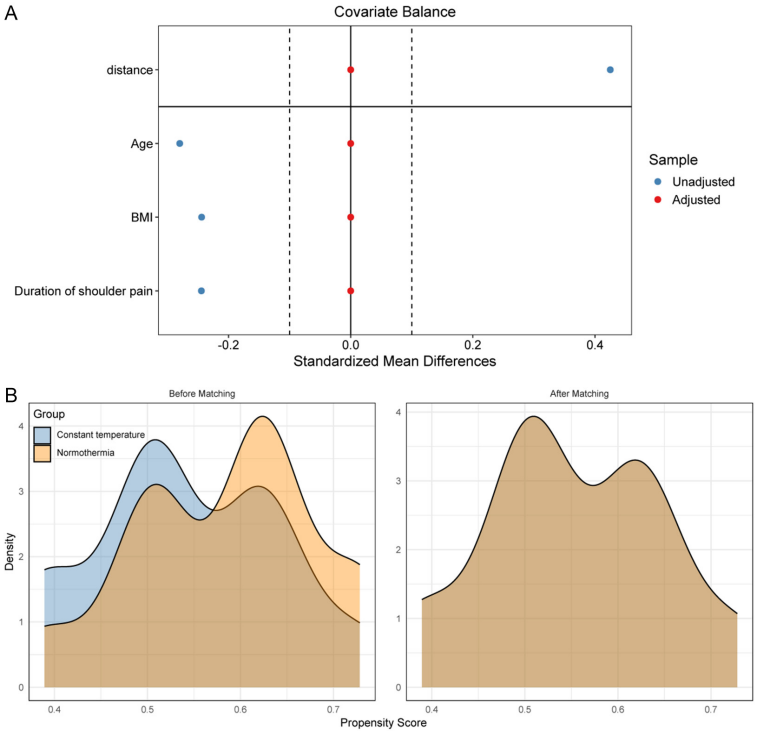


Figure 3. PSM Pre- and Post-matching covariate balance analysis. A. Covariate balance assessment before and after PSM. B. Distribution comparison before and after PSM. Note: PSM, Propensity Score Matching; BMI, Body Mass Index.

compared with preoperative values ($P < 0.05$), with further improvement from 3 to 6 months ($P < 0.05$) (**Table 10**).

Comparison of prognostic outcomes after PSM

Among 328 matched patients, 149 achieved favorable prognosis (UCLA ≥ 26 and ASES ≥ 85 at 6 months), while 179 had unfavorable outcomes. **Figure 4** shows the distribution based on both scores, with 25 patients (7.6%) failing to meet either criterion. Baseline characteristics by prognosis group are presented in Table S2.

Comparison of independent risk factors for prognosis after PSM

Post-PSM univariate logistic regression identified BMI (OR = 0.592, 95% CI: 0.357-0.984, P = 0.043) as significantly

Table 6. Comparison of baseline characteristics Post-PSM [n (%)]

Factor	Total	Room Temperature Group (n = 164)	Isothermic Group (n = 164)	Test Statistic	*P*-value
Age					
≥ 60 years	196 (59.76%)	98 (59.76%)	98 (59.76%)	< 0.001	1
< 60 years	132 (40.24%)	66 (40.24%)	66 (40.24%)		
Gender					
Male	185 (56.40%)	91 (55.49%)	94 (57.32%)	0.112	0.738
Female	143 (43.60%)	73 (44.51%)	70 (42.68%)		
BMI					
≥ 24	86 (26.22%)	43 (26.22%)	43 (26.22%)	< 0.001	1
< 24	242 (73.78%)	121 (73.78%)	121 (73.78%)		
Diabetes					
Yes	53 (16.16%)	24 (14.63%)	29 (17.68%)	0.563	0.453
No	275 (83.84%)	140 (85.37%)	135 (82.32%)		
Hypertension					
Yes	68 (20.73%)	34 (20.73%)	34 (20.73%)	< 0.001	1
No	260 (79.27%)	130 (79.27%)	130 (79.27%)		
Smoking History					
Yes	182 (55.49%)	86 (52.44%)	96 (58.54%)	1.234	0.267
No	146 (44.51%)	78 (47.56%)	68 (41.46%)		
Alcohol History					
Yes	75 (22.87%)	36 (21.95%)	39 (23.78%)	0.156	0.693
No	253 (77.13%)	128 (78.05%)	125 (76.22%)		
Shoulder Pain Duration					
≥ 6 months	182 (55.49%)	91 (55.49%)	91 (55.49%)	< 0.001	1
< 6 months	146 (44.51%)	73 (44.51%)	73 (44.51%)		
Shoulder Pain Location					
Left	187 (57.01%)	90 (54.88%)	97 (59.15%)	0.61	0.435
Right	141 (42.99%)	74 (45.12%)	67 (40.85%)		
Osteoporosis					
Yes	41 (12.50%)	22 (13.41%)	19 (11.59%)	0.251	0.616
No	287 (87.50%)	142 (86.59%)	145 (88.41%)		
Rotator Cuff Tear Length					
≥ 2 cm	170 (51.83%)	84 (51.22%)	86 (52.44%)	0.049	0.825
< 2 cm	158 (48.17%)	80 (48.78%)	78 (47.56%)		
Operative Time					
≥ 60 min	212 (64.63%)	105 (64.02%)	107 (65.24%)	0.053	0.817
< 60 min	116 (35.37%)	59 (35.98%)	57 (34.76%)		
Intraoperative Blood Loss					
≥ 60 mL	147 (44.82%)	80 (48.78%)	67 (40.85%)	2.083	0.149
< 60 mL	181 (55.18%)	84 (51.22%)	97 (59.15%)		

Note: PSM, Propensity Score Matching; BMI, Body Mass Index.

associated with prognosis. No other variables, including treatment protocol, age, gender, comorbidities, pain characteristics, osteoporosis, tear length, operative details, or postoperative complications, were significant (all P > 0.05) (**Figure 5**).

Table 7. Comparison of postoperative joint swelling Post-PSM [Median (Interquartile Range)]

Variable	Room Temperature Group (n = 164)	Isothermic Group (n = 164)	Test Statistic	*P*-value
Preoperative circumference	45.13 ± 2.03	45.52 ± 2.88	1.899	0.058
Postoperative day 1 circumference	50.03 ± 3.00*	49.89 ± 2.50*	0.671	0.502
Postoperative day 7 circumference	49.10 ± 3.52*,#	46.32 ± 2.69*,#	7.276	< 0.001
Postoperative day 14 circumference	47.49 ± 2.62*,#,&	45.65 ± 2.02#	7.011	< 0.001

Note: * indicates P < 0.05 compared to preoperative; # indicates P < 0.05 compared to postoperative day 1; & indicates P < 0.05 compared to postoperative day 7. PSM, Propensity Score Matching.

Table 8. Comparison of postoperative pain scores Post-PSM [Median (Interquartile Range)]

Variable	Room Temperature Group (n = 164)	Isothermic Group (n = 164)	Test Statistic	*P*-value
Preoperative VAS	6.96 ± 1.59	7.04 ± 1.42	0.441	0.659
Postoperative 2 h VAS	1.96 ± 0.97*	2.12 ± 1.05*	1.77	0.077
Postoperative 12 h VAS	5.55 ± 1.28*,#	4.05 ± 1.06*,#	10.03	< 0.001
Postoperative 24 h VAS	3.54 ± 0.89*,#,&	3.43 ± 1.10*,#,&	0.67	0.503

Note: * indicates P < 0.05 compared to preoperative; # indicates P < 0.05 compared to postoperative 2 h; & indicates P < 0.05 compared to postoperative 12 h. PSM, Propensity Score Matching; VAS, Visual Analog Scale.

Table 9. Comparison of postoperative hypothermia and shivering Post-PSM [n (%)]

Factor	Total	Room Temperature Group (n = 164)	Isothermic Group (n = 164)	Test Statistic	*P*-value
Postoperative Hypothermia					
Yes	22 (6.71%)	15 (9.15%)	7 (4.27%)	3.118	0.077
No	306 (93.29%)	149 (90.85%)	157 (95.73%)		
Postoperative Shivering					
Yes	7 (2.13%)	5 (3.05)	2 (1.22%)	-	0.448
No	321 (97.87%)	159 (96.95%)	162 (98.78%)		

Note: PSM, Propensity Score Matching.

Table 10. Comparison of postoperative UCLA and ASES scores Post-PSM [Median (Interquartile Range) or Mean ± Standard Deviation]

Variable	Room Temperature Group (n = 164)	Isothermic Group (n = 164)	Test Statistic	*P*-value
UCLA				
Preoperative	15.51 ± 2.42	15.56 ± 2.42	0.444	0.657
3 months postoperative	21.19 ± 2.37*	21.27 ± 2.41*	0.22	0.826
6 months postoperative	28.86 ± 3.42*,#	28.48 ± 3.50*,#	1.025	0.306
ASES				
Preoperative	55.27 ± 4.83	55.10 ± 3.73	0.44	0.66
3 months postoperative	75.66 ± 5.38*	75.98 ± 4.93*	0.568	0.571
6 months postoperative	85.41 ± 5.25*,#	85.74 ± 5.35*,#	0.531	0.595

Note: * indicates P < 0.05 compared to preoperative; # indicates P < 0.05 compared to 3 months postoperative. PSM, Propensity Score Matching; UCLA, University of California, Los Angeles Shoulder Score; ASES, American Shoulder and Elbow Surgeons Score.

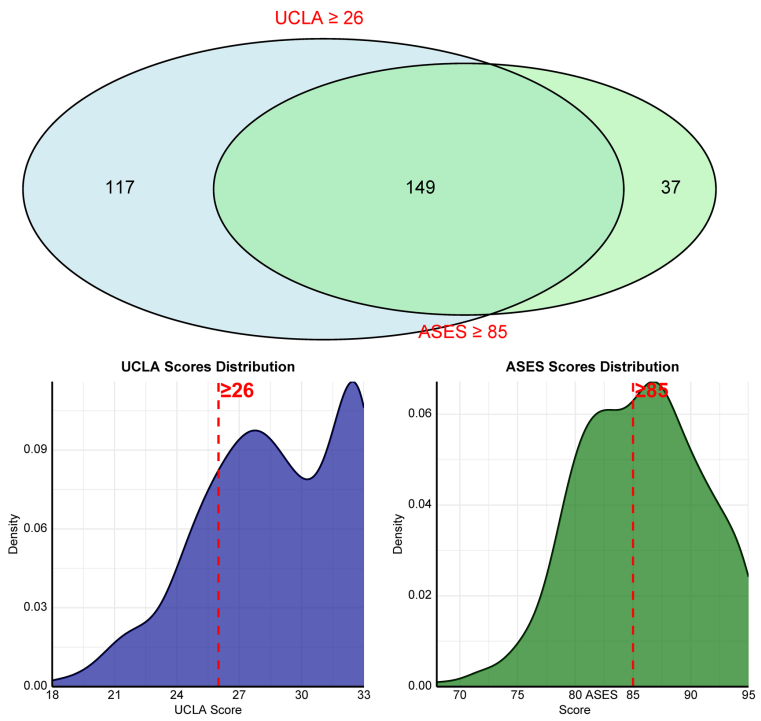


Figure 4. Patient distribution based on UCLA and ASES score thresholds and score distributions after PSM. Note: The figure shows the distribution of patients achieving favorable scoring standards, with an additional 25 patients (7.6%) failing to meet both scoring criteria. PSM, Propensity Score Matching; UCLA, University of California, Los Angeles Shoulder Score; ASES, American Shoulder and Elbow Surgeons Score.

Multivariate analysis confirmed BMI (OR = 0.592, 95% CI: 0.354-0.978, P = 0.043) as an independent prognostic factor (**Figure 5**).

Discussion

The influence of irrigation fluid temperature on postoperative recovery after arthroscopic rotator cuff repair has historically lacked robust evidence-based support. Prior studies, often limited by small sample sizes and insufficient control of confounding factors, have yielded inconsistent results. Irrigation fluid temperature is a modifiable intraoperative variable that may affect the local tissue microenvironment, with potential implications for postoperative inflammation, vascular function, and pain perception. By applying PSM to control for key confounders - including age, BMI, and duration of shoulder pain - our study provides a more reliable framework for assessing its clinical impact, thereby improving the objectivity and accuracy of findings and addressing a significant gap in the literature.

Our results show that isothermic irrigation fluid at 37°C significantly reduced joint swelling at postoperative days 7 and 14 and lowered pain scores at 12 hours after surgery. These findings are consistent with the systematic review and meta-analysis by Lin et al. [8], which reported that warm irrigation fluid mitigates core temperature decline, reduces hypothermia incidence, and decreases shivering. The use of PSM effectively balanced baseline characteristics between the isothermic and room-temperature groups, ensuring that outcome differences were attributable to irrigation fluid temperature. Notably, while pre-PSM baseline imbalances (e.g., hypothermia incidence) could have confounded the results, post-PSM analyses confirmed that reductions in swelling and pain remained statistically significant, reinforcing the independent effect of isothermic irrigation on early recovery.

Physiologically, room-temperature irrigation (22-24°C) creates a 13-15°C gradient with core body temperature, which may impair recovery via multiple mechanisms. Cold irrigation can induce local vasoconstriction, reducing microcirculatory perfusion, oxygen delivery, and clearance of inflammatory metabolites, thereby exacerbating edema. Pan et al. [14] reported hypothermia in 94% of patients receiving room-temperature irrigation versus 27% in the warm group, along with significantly lower serum IL-6 and drainage cytokine levels in the latter. Other studies [15] showed that cartilage explants exposed to 4°C or 24°C saline have reduced RNA synthesis, lactate production, and proteoglycan content, indicating detrimental effects on chondrocyte function. Cold stimulation also activates the sympathetic nervous system, triggering catecholamine release and further vasoconstriction. Interestingly, Charoenwisetsin et al. [16] found lower pain

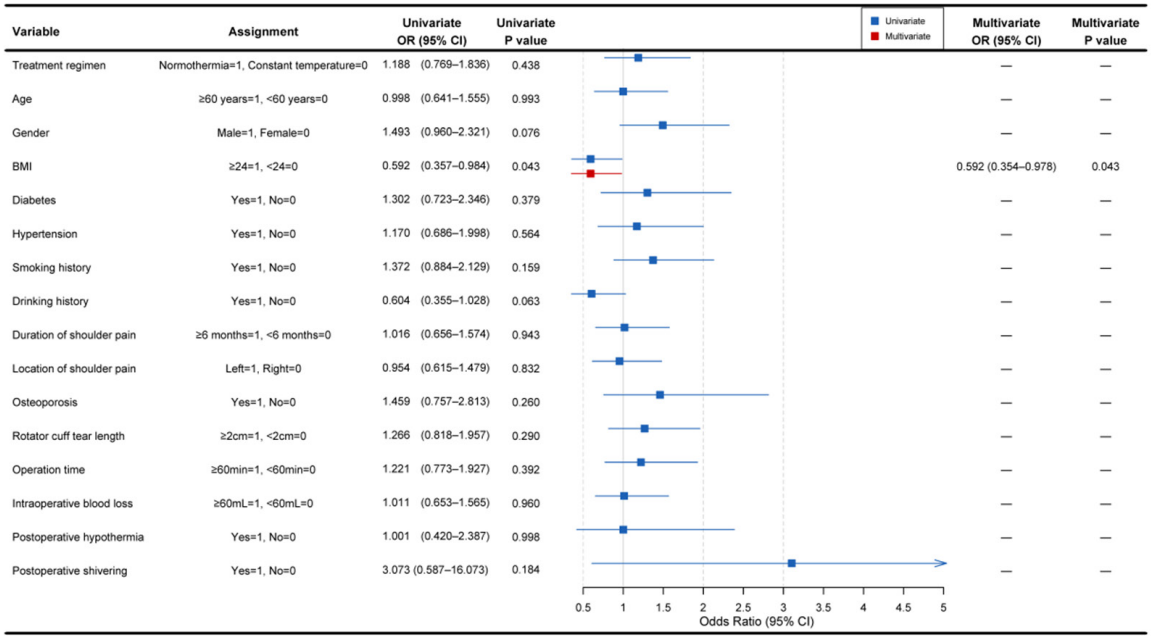


Figure 5. Post-PSM independent risk factor screening results for patient prognosis. Note: PSM, Propensity Score Matching; OR, Odds Ratio; CI, Confidence Interval; BMI, Body Mass Index.

scores within 28 hours post-knee replacement in the cold irrigation group, suggesting thermal modulation can differentially influence pain perception.

Cold exposure may also intensify local inflammation. In spinal surgery, warm saline irrigation has been associated with lower CRP, IL-6, and serum amyloid A levels, along with reduced postoperative pain [17]. Although our study did not measure inflammatory markers, such mechanisms warrant future investigation. Preoperative pain severity, psychological state, and baseline function have been identified as independent predictors of chronic postsurgical pain [18], which affects 30.4% of patients. Isothermic irrigation may stabilize local blood flow, promote endogenous opioid release, and modulate pain transmission. Supporting this, He et al. [19] demonstrated that 37°C irrigation during ureteroscopy reduced postoperative fever and shivering compared to 17°C irrigation.

The temporal pattern observed - greatest swelling reduction at days 7 and 14 and pain relief most evident at 12 hours - likely reflects differences in physiological processes. Warm irrigation minimizes cartilage and chondrocyte damage [20], while vascular and inflammatory responses evolve over days, and neurogenic pain pathways respond more immediately.

In our multivariate regression, BMI emerged as an independent prognostic factor for 6-month recovery. This suggests a protective association, which contrasts with previous studies linking obesity to worse outcomes. For example, Kessler et al. [21] found no difference between obese and non-obese patients, possibly as a result of small sample size, whereas Berglund et al. [22] and meta-analyses [23] reported worse pain, function, higher complication rates, and increased readmissions among obese patients. Obesity-related factors - such as poor adipose vascularization, low oxygen tension, and impaired nutrient delivery - can hinder tendon-bone healing. Chronic low-grade inflammation, marked by elevated IL-6 and TNF-α, may also interfere with repair. Parnes et al. [24] documented inferior pain and function scores and limited internal rotation in obese patients over 4 years, while biomechanical studies indicate excess weight increases joint loading, potentially compromising remodeling [25]. Given this discrepancy, further investigation is needed to clarify BMI's role in postoperative prognosis in this surgical context.

Cline et al. [26] identified preoperative smoking as a significant factor associated with worse

pain, ASES, and Single Assessment Numeric Evaluation scores, underscoring the multifactorial nature of postoperative outcomes. In our pre-PSM analysis, age, pain duration, and osteoporosis were significantly different between groups; however, only BMI remained significant after PSM. Literature [27] reports that, in chronic rotator cuff tear repair, functional improvement was 75% in diabetic patients versus 83.9% in non-diabetic patients, and 76.6% in obese patients versus 87.9% in non-obese patients. These findings reinforce the prognostic relevance of BMI and support its use for preoperative risk stratification. Patients with BMI ≥ 24 kg/m^2 may benefit from targeted weight reduction and tailored postoperative rehabilitation programs.

In our original cohort, baseline differences in age, BMI, and pain duration between the room-temperature and isothermic groups reflect a limitation inherent to retrospective studies, where non-randomized allocation risks confounding bias. Moorthy et al. [12] demonstrated that UCLA shoulder scores are a strong predictor of treatment success in a 214-patient study, emphasizing the need for appropriate functional outcome measures. Post-PSM, differences in postoperative hypothermia and shivering were no longer significant, suggesting that pre-matching differences were driven by confounders rather than irrigation fluid temperature itself.

Evidence from urological surgery [28] indicates that peri-induction warming and warmed intravenous fluids improve thermal comfort but do not completely prevent intraoperative hypothermia. Hypothermia is a multifactorial outcome influenced by anesthesia depth, intraoperative blood loss, irrigation fluid temperature, and ambient operating room conditions. Oh et al. [29] found no significant difference in perioperative hypothermia between 36°C and room-temperature irrigation during arthroscopic shoulder surgery, possibly due to variations in surgical duration and irrigation volume. By balancing these factors, our PSM analysis likely contributed to comparable postoperative temperature outcomes between groups. Similarly, the absence of a post-PSM difference in shivering suggested that shivering is more closely related to individual thermoregulatory variability, anesthetic metabolism, and intraoperative exposure than to irrigation fluid temperature alone.

Patel et al. [13] reported minimal differences in 1- and 2-year ASES scores in a large cohort of 1,567 patients, highlighting the importance of long-term follow-up to determine clinical significance. In our study, the balanced post-PSM outcomes for hypothermia and shivering underscore the necessity of accounting for multifactorial influences in thermoregulation research.

Despite these strengths, limitations remain. As a retrospective study, our study was subject to selection and information bias, and PSM cannot fully account for unmeasured confounders compared with randomized controlled trials. The single-center design and modest sample size further limited generalizability. Additionally, the 6-month follow-up period may have been insufficient to assess long-term functional outcomes. Future research should include multicenter RCTs with extended follow-up to evaluate long-term functional recovery and re-tear rates, thereby providing higher-level evidence to refine clinical recommendations.

Conclusions

Isothermic irrigation fluid significantly reduces early postoperative swelling and pain but has no substantial effect on long-term functional recovery. Its effect on postoperative hypothermia and shivering appears minimal. BMI was identified as an independent prognostic factor, warranting its consideration for preoperative risk assessment.

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Disclosure of conflict of interest

None.

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Comparison of baseline characteristics between patients with good and poor prognosis before PSM

Before PSM, significant differences were observed in multiple baseline characteristics between patients with poor and good prognosis. Regarding age distribution, the proportion of patients ≥ 60 years was significantly lower in the poor prognosis group compared to the good prognosis group (53.18% vs 73.16%, P < 0.001). In terms of gender distribution, the proportion of male patients was lower in the poor prognosis group than in the good prognosis group (51.36% vs 61.05%, P = 0.049). BMI distribution showed that the proportion of patients with BMI ≥ 24 was significantly lower in the poor prognosis group compared to the good prognosis group (23.64% vs 41.58%, P < 0.001). For shoulder pain duration, the proportion of patients with ≥ 6 months duration was significantly lower in the poor prognosis group than in the good prognosis group (51.36% vs 65.26%, P = 0.004). Regarding osteoporosis prevalence, the poor prognosis group had a significantly lower rate than the good prognosis group (8.64% vs 19.47%, P = 0.001). In rotator cuff tear length distribution, the proportion of tears ≥ 2 cm was significantly lower in the poor prognosis group compared to the good prognosis group (44.09% vs 60.53%, P < 0.001). No significant differences were observed between the two groups in treatment regimen, diabetes, hypertension, smoking history, alcohol history, shoulder pain location, operative time, intraoperative blood loss, postoperative hypothermia, and postoperative shivering (P > 0.05) (Table S1).

Table S1. Comparison of baseline data between patients with good prognosis and poor prognosis before PSM

Factor	Total	Poor prognosis (n = 220)	Good prognosis (n = 190)	Test Statistic	*P*-value
Treatment regimen					
Constant temperature	232 (56.59%)	118 (53.64%)	114 (60.00%)	1.681	0.195
Normothermia	178 (43.41%)	102 (46.36%)	76 (40.00%)		
Age					
≥ 60 years	256 (62.44%)	117 (53.18%)	139 (73.16%)	17.347	< 0.001
< 60 years	154 (37.56%)	103 (46.82%)	51 (26.84%)		
Gender					
Male	229 (55.85%)	113 (51.36%)	116 (61.05%)	3.882	0.049
Female	181 (44.15%)	107 (48.64%)	74 (38.95%)		
BMI					
≥ 24	131 (31.95%)	52 (23.64%)	79 (41.58%)	15.096	< 0.001
< 24	279 (68.05%)	168 (76.36%)	111 (58.42%)		
Diabetes					
Yes	65 (15.85%)	32 (14.55%)	33 (17.37%)	0.609	0.435
No	345 (84.15%)	188 (85.45%)	157 (82.63%)		
Hypertension					
Yes	85 (20.73%)	44 (20.00%)	41 (21.58%)	0.155	0.694
No	325 (79.27%)	176 (80.00%)	149 (78.42%)		
Smoking History					
Yes	228 (55.61%)	115 (52.27%)	113 (59.47%)	2.142	0.143
No	182 (44.39%)	105 (47.73%)	77 (40.53%)		
Alcohol History					
Yes	95 (23.17%)	58 (26.36%)	37 (19.47%)	2.719	0.099
No	315 (76.83%)	162 (73.64%)	153 (80.53%)		
Shoulder Pain Duration					
≥ 6 months	237 (57.80%)	113 (51.36%)	124 (65.26%)	8.075	0.004
< 6 months	173 (42.20%)	107 (48.64%)	66 (34.74%)		
Shoulder Pain Location					
Left	233 (56.83%)	126 (57.27%)	107 (56.32%)	0.038	0.845
Right	177 (43.17%)	94 (42.73%)	83 (43.68%)		

Osteoporosis					
Yes	56 (13.66%)	19 (8.64%)	37 (19.47%)	10.153	0.001
No	354 (86.34%)	201 (91.36%)	153 (80.53%)		
Rotator Cuff Tear Length					
≥ 2 cm	212 (51.71%)	97 (44.09%)	115 (60.53%)	11.029	< 0.001
< 2 cm	198 (48.29%)	123 (55.91%)	75 (39.47%)		
Operative Time					
≥ 60 min	261 (63.66%)	136 (61.82%)	125 (65.79%)	0.695	0.404
< 60 min	149 (36.34%)	84 (38.18%)	65 (34.21%)		
Intraoperative Blood Loss					
≥ 60 mL	186 (45.37%)	102 (46.36%)	84 (44.21%)	0.191	0.662
< 60 mL	224 (54.63%)	118 (53.64%)	106 (55.79%)		
Postoperative hypothermia					
Yes	29 (7.07%)	15 (6.82%)	14 (7.37%)	0.047	0.828
No	381 (92.93%)	205 (93.18%)	176 (92.63%)		
Postoperative shivering					
Yes	8 (1.95%)	6 (2.73%)	2 (1.05%)		0.295
No	402 (98.05%)	214 (97.27%)	188 (98.95%)		

Note: BMI, Body Mass Index.

Comparison of baseline characteristics between patients with good and poor prognosis after PSM

After propensity score matching, baseline characteristics between the two groups were significantly improved, with most variables achieving good balance. After matching, only BMI distribution showed a slight difference, with the poor prognosis group having a slightly higher proportion of patients with BMI ≥ 24 compared to the good prognosis group (30.73% vs 20.81%, P = 0.042). No significant differences were observed between the two groups in age, gender, treatment regimen, diabetes, hypertension, smoking history, alcohol history, shoulder pain duration, shoulder pain location, osteoporosis, rotator cuff tear length, operative time, intraoperative blood loss, postoperative hypothermia, and postoperative shivering (P > 0.05), indicating good comparability between the matched samples (Table S2).

Table S2. Comparison of baseline data between patients with good prognosis and poor prognosis after PSM

Factor	Total	Poor prognosis (n = 179)	Good prognosis (n = 179)	Test Statistic	*P*-value
Treatment regimen					
Constant temperature	164 (50.00%)	86 (48.04%)	78 (52.35%)	0.603	0.438
Normothermia	164 (50.00%)	93 (51.96%)	71 (47.65%)		
Age					
≥ 60 years	196 (59.76%)	107 (59.78%)	89 (59.73%)	0.000	0.993
< 60 years	132 (40.24%)	72 (40.22%)	60 (40.27%)		
Gender					
Male	185 (56.40%)	93 (51.96%)	92 (61.74%)	3.169	0.075
Female	143 (43.60%)	86 (48.04%)	57 (38.26%)		
BMI					
≥ 24	86 (26.22%)	55 (30.73%)	31 (20.81%)	4.137	0.042
< 24	242 (73.78%)	124 (69.27%)	118 (79.19%)		
Diabetes					
Yes	53 (16.16%)	26 (14.53%)	27 (18.12%)	0.776	0.378
No	275 (83.84%)	153 (85.47%)	122 (81.88%)		

Hypertension					
Yes	68 (20.73%)	35 (19.55%)	33 (22.15%)	0.333	0.564
No	260 (79.27%)	144 (80.45%)	116 (77.85%)		
Smoking History					
Yes	182 (55.49%)	93 (51.96%)	89 (59.73%)	1.991	0.158
No	146 (44.51%)	86 (48.04%)	60 (40.27%)		
Alcohol History					
Yes	75 (22.87%)	48 (26.82%)	27 (18.12%)	3.485	0.062
No	253 (77.13%)	131 (73.18%)	122 (81.88%)		
Shoulder Pain Duration					
≥ 6 months	182 (55.49%)	99 (55.31%)	83 (55.70%)	0.005	0.943
< 6 months	146 (44.51%)	80 (44.69%)	66 (44.30%)		
Shoulder Pain Location					
Left	187 (57.01%)	103 (57.54%)	84 (56.38%)	0.045	0.832
Right	141 (42.99%)	76 (42.46%)	65 (43.62%)		
Osteoporosis					
Yes	41 (12.50%)	19 (10.61%)	22 (14.77%)	1.281	0.258
No	287 (87.50%)	160 (89.39%)	127 (85.23%)		
Rotator Cuff Tear Length					
≥ 2 cm	170 (51.83%)	88 (49.16%)	82 (55.03%)	1.123	0.289
< 2 cm	158 (48.17%)	91 (50.84%)	67 (44.97%)		
Operative Time					
≥ 60 min	212 (64.63%)	112 (62.57%)	100 (67.11%)	0.735	0.391
< 60 min	116 (35.37%)	67 (37.43%)	49 (32.89%)		
Intraoperative Blood Loss					
≥ 60 mL	147 (44.82%)	80 (44.69%)	67 (44.97%)	0.002	0.960
< 60 mL	181 (55.18%)	99 (55.31%)	82 (55.03%)		
Postoperative hypothermia					
Yes	22 (6.71%)	12 (6.70%)	10 (6.71%)	0.000	0.998
No	306 (93.29%)	167 (93.30%)	139 (93.29%)		
Postoperative shivering					
Yes	7 (2.13%)	2 (1.12%)	5 (3.36%)		0.252
No	321 (97.87%)	177 (98.88%)	144 (96.64%)		

Note: BMI, Body Mass Index.