Association of an Intensive Multimodal Perioperative Management Bundle With Short-Term Recovery After Surgery for Trimalleolar Fractures: A Single-Center Retrospective Cohort Study

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AIM: To examine the association between receipt of an intensive multimodal perioperative management bundle and short-term functional recovery, pain, and clinical outcomes in patients undergoing surgery for trimalleolar fractures.

METHODS: This single-center retrospective cohort included 84 patients who underwent open reduction and internal fixation for trimalleolar fractures between September 2023 and September 2025. The intensive management bundle was a pre-existing standardized routine-care pathway rather than a research intervention developed for this study. Patients were classified retrospectively according to contemporaneous medical and nursing records: 43 patients who received routine management were assigned to a routine-management group, and 41 who received the intensive bundle were assigned to an intensive-pathway group. The investigators did not prospectively enroll patients, assign pathways, deliver study-specific interventions, or collect research-specific data. Primary outcomes were the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale and Visual Analog Scale (VAS) scores; secondary outcomes included first out-of-bed mobilization, length of hospital stay, hospitalization costs, patient satisfaction, and deep vein thrombosis (DVT). Unadjusted mean differences or odds ratios (ORs) with 95% confidence intervals (CIs) were calculated, and longitudinal AOFAS and VAS data were analyzed using mixed-design repeated-measures analysis of variance (RM-ANOVA). Because the components were delivered together, no component-specific effect was estimated.

RESULTS: No baseline variable differed significantly between groups, although the absence of statistical significance did not establish covariate balance. In unadjusted analyses, receipt of the intensive bundle was associated with earlier first out-of-bed mobilization (mean difference [MD], −22.80 h; 95% confidence interval [CI], −26.48 to −19.12), shorter hospitalization (MD, −3.30 days; 95% CI, −4.14 to −2.46), lower hospitalization costs (MD, −13,114 CNY (1 USD = 7.1429 CNY); 95% CI, −14,979 to −11,249), and higher patient satisfaction (OR, 5.16; 95% CI, 1.04–25.56). VAS scores were lower in the intensive-pathway group at 1 week (3.9 ± 0.9 vs. 4.8 ± 1.0), 1 month (1.3 ± 0.7 vs. 3.2 ± 1.0), and 3 months (1.0 (0.0, 1.0) vs. 2.0 (1.0, 2.0)) postoperatively (all Bonferroni-adjusted $p < 0.001$); RM-ANOVA showed significant group, time, and group-by-time interaction effects for both AOFAS and VAS scores. DVT occurred in 3/41 (7.3%) patients in the intensive-pathway group and 8/43 (18.6%) in the routine-management group, and the difference was not statistically significant (OR, 0.35; 95% CI, 0.08–1.41). These findings represent associations with the integrated bundle and cannot be attributed independently to preoperative optimization, ankle-pump exercise, analgesia, mobilization, or follow-up.

CONCLUSIONS: In this retrospective cohort, receipt of an intensive multimodal perioperative management bundle was associated with earlier mobilization, shorter hospitalization, lower hospitalization costs, and more favorable short-term functional and pain trajectories. Because the bundle contained multiple simultaneously delivered components, the study cannot determine the independent efficacy of preoperative optimization, ankle-pump exercise, or any other individual measure. In addition, pathway allocation was non-random and the estimates were unadjusted; therefore, the findings should be interpreted as associations rather than definitive causal effects.

Keywords: trimalleolar fracture; multimodal perioperative management; preoperative optimization; rehabilitation; AOFAS score; deep vein thrombosis

Introduction

A trimalleolar fracture involves the medial, lateral, and posterior malleoli and is generally considered an unstable injury that commonly requires operative treatment [1]. Recent single-center data have further characterized demographic and injury-related risk patterns in patients with trimalleolar fractures [2]. The multi-fragmentary fracture pattern and associated soft-tissue injury can complicate surgical management; postoperative infection and incomplete short-term recovery remain relevant concerns after operative treatment of malleolar fractures [3,4]. Rehabilitation strategies after ankle-fracture surgery remain heterogeneous, with uncertainty regarding the optimal timing and intensity of exercise and weight bearing [5]. Deep

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vein thrombosis (DVT) is also an important postoperative concern. In a cohort encompassing foot and ankle surgery generally—not trimalleolar fractures specifically—screening ultrasonography detected DVT in 14.7% of patients, predominantly in calf muscular veins [6].

Rather than evaluating a formal enhanced recovery after surgery (ERAS) program, the present study examined an integrated routine-care bundle comprising one-day preoperative optimization, structured postoperative ankle-pump exercise (APE), individualized analgesia, early mobilization, drain and catheter policies, and post-discharge rehabilitation follow-up. The preoperative component consisted of nutritional risk screening and support, health education, routine anesthesia consultation, and assistive-device training. Because surgery occurred approximately 5 days after injury, this component is more accurately termed preoperative optimization than conventional prehabilitation. Conventional orthopedic prehabilitation research generally evaluates structured programs delivered over a longer preoperative period and may include physical, nutritional, and psychological components [7,8].

APE was incorporated into both management pathways, although the routine-management records generally documented only basic exercise instruction. The clinically relevant contrast in the present cohort was therefore not between APE and no APE, but between a quantified, supervised, and progressively intensified APE program and no such structured program, with the former embedded within a broader multimodal perioperative pathway. This distinction is important because the experimental group also received several simultaneously delivered components, including individualized pain management, early mobilization, drain and catheter policies, and structured post-discharge follow-up.

Evidence remains limited regarding whether receipt of such an integrated multimodal pathway is associated with short-term recovery after open reduction and internal fixation of trimalleolar fractures when routine management already includes basic exercise guidance. This single-center retrospective cohort therefore examined associations between the intensive bundle and functional recovery, pain, mobilization, hospitalization, patient satisfaction, and DVT. Because all components were delivered simultaneously, the study evaluated the bundle as a whole and was not designed to estimate the independent contribution of preoperative optimization, APE, analgesia, early mobilization, or follow-up. Given the observational design, the analysis was intended to identify associations rather than establish causality.

Methods

Study Design and Data Source

The single-center retrospective cohort study included patients treated between September 2023 and September 2025. The intensive multimodal pathway was a standardized clinical pathway applied prospectively as part of routine care; however, the present research was initiated after clinical care had been delivered. The investigators did not prospectively recruit patients, assign them to management pathways, modify treatment, or perform study-specific real-time monitoring of adherence. Pathway exposure, prescribed interventions, contemporaneously recorded implementation, and outcomes were extracted retrospectively from existing electronic medical records, medication-administration records, nursing rehabilitation records, and routine follow-up records. The study protocol was approved by the Ethics Committee of Wuhan No.8 Hospital (Wuhan Anorectal Hospital) (Ethics Approval No.: HEC-PJ-20251022-001) and complied with the Declaration of Helsinki. Because the study used existing de-identified records and involved no additional research intervention, the requirement for written informed consent was waived by the Ethics Committee.

The source population comprised consecutive adult patients with imaging-confirmed trimalleolar fractures who underwent open reduction and internal fixation (ORIF) at the study center during the study period. Cases were identified in chronological order from the electronic surgical and inpatient databases. The focused database search identified 84 consecutive records meeting the diagnostic and surgical criteria; after application of the predefined inclusion and exclusion criteria, all 84 remained eligible. The last included patient underwent surgery on September 1, 2025, and the final routine 3-month follow-up was completed on December 1, 2025. The retrospective research and data extraction were initiated in January 2026, after clinical treatment and routine 3-month follow-up had been completed for all included patients. Complete 3-month follow-up records were available for all 84 eligible cases, and no additional case was excluded from the analytic cohort.

Inclusion and Exclusion Criteria

Inclusion criteria: ① age 18–75 years; ② imaging-confirmed trimalleolar fracture (medial, lateral, and posterior malleoli); ③ scheduled for elective open reduction and internal fixation; ④ clear consciousness and ability to cooperate with rehabilitation training; ⑤ American Society of Anesthesiologists (ASA) physical status classification I or II.

Exclusion criteria: ① concurrent severe cardiopulmonary insufficiency; ② a history of surgery on the ipsilateral ankle; ③ concurrent peripheral vascular disease or history of lower-extremity deep vein thrombosis; ④ severe osteoporosis (T-score <−3.5); ⑤ cognitive impairment precluding cooperation with follow-up; ⑥ concomitant fractures requiring simultaneous surgery.

Grouping Method

Patients were retrospectively classified according to the perioperative management documented contemporaneously in their medical records. Patients who received routine perioperative management were included in the routine-

management group, whereas those who received the intensive multimodal perioperative management bundle (hereafter, the intensive pathway) were included in the intensive-pathway group. Classification was based on routine clinical pathway documentation, medication-administration records, nursing rehabilitation records, and discharge or follow-up records; the detailed protocol was neither reconstructed from patient recall nor established retrospectively after the outcomes were known. Entry into either pathway reflected management selected and delivered during routine clinical care rather than a prespecified research allocation procedure. The records did not contain a uniform, prospectively documented rationale for pathway selection; consequently, the relative contributions of clinician judgment, patient preference or suitability, pathway availability, and other operational factors could not be reconstructed reliably. The available records also did not permit reliable determination of whether the intensive pathway was introduced at a single fixed calendar point, and secular changes throughout the September 2023–September 2025 study period could not be excluded. Ultimately, 43 patients were included in the routine-management group and 41 in the intensive-pathway group. No research-specific randomization, allocation concealment, or blinding was performed.

Definitions of Perioperative Management Protocols

Control Group (Routine Perioperative Management)

Patients received the hospital's routine perioperative management, including standard pre-admission and preoperative education, postoperative elevation of the affected limb and monitoring for swelling, physician-ordered analgesia, general instruction on basic ankle-pump and toe flexion-extension exercises, guidance on crutch-assisted walking, and discharge education. In the routine-management records, APE was generally documented as exercise instruction rather than as a standardized dose. The initiation time, repetitions per session, daily frequency, supervision method, and completion were not recorded consistently enough to quantify the actual APE exposure in this group. The verifiable contrast was therefore that the routine-management group did not receive the intensive pathway's quantified hourly and daily targets, routine bedside supervision and documentation, structured progression, or intensive post-discharge APE follow-up. This limitation in reconstructing the intensity of routine APE is acknowledged below.

Experimental Group (Intensive Multimodal Perioperative Management Bundle)

Building upon routine management, the experimental group received a pre-existing standardized multimodal perioperative management bundle that included short-term preoperative optimization, quantified APE prescriptions, nutritional support, health education, pain management, early mobilization, and post-discharge follow-up. The schedule below describes the standardized care prescribed by the routine clinical pathway and recorded contemporaneously in the clinical record. It should not be interpreted as a prospectively designed research intervention or as evidence that every patient completed every prescribed session. Because the components were delivered together, the present study did not isolate the independent effects of APE, analgesia, surgical adjunct policies, mobilization, or follow-up; nor did it estimate a patient-level delivered APE dose in the routine-management group.

(1) One day before surgery: As specified by the routine clinical pathway, the Department of Nutrition conducted nutritional risk screening (NRS-2002) and formulated individualized nutritional plans, including protein and vitamin D supplementation, for patients identified as being at nutritional risk. Systematic health education covered the surgical process, anesthesia methods, expected postoperative rehabilitation, and pain management strategies. Rehabilitation therapists provided instruction on the use of crutches and walkers, and anesthesiologists performed routine preoperative visits. In consultation with the surgical team, the pathway specified avoidance of routine intraoperative drainage and selective urinary catheterization when the estimated procedure duration exceeded 2 hours or regional anesthesia was expected to affect urinary function. These activities were identified retrospectively from the relevant routine clinical documentation. This one-day component is referred to as preoperative optimization rather than conventional multi-week prehabilitation.

(2) Day of surgery: When patient-controlled analgesia (PCA) was prescribed by the anesthesia team, nurses explained its use before surgery or after recovery from anesthesia. The operating surgeon discussed the planned fixation strategy and the anticipated implant types with the patient during the preoperative consent process; no counseling was performed during anesthesia or the sterile operative procedure. Analgesic selection, dosing, route of administration, and subsequent adjustment were based on individual physician orders and guided by pain intensity, contraindications, and tolerability. The retrospective analytic dataset did not contain a single uniform drug-level regimen suitable for agent- or dose-specific comparison between the two groups.

(3) Postoperative day 1: The patient was placed supine with the affected limb elevated 15°–20° above heart level, and assistance was provided for heel-to-knee alignment exercises. The primary nurse assessed pain every 4 hours using the Numeric Rating Scale (NRS), and analgesia was adjusted under physician orders when the pain NRS exceeded 4. Early urinary-catheter removal, generally within 24 hours, was encouraged. The prescribed APE schedule commenced 12–24 hours after surgery: active dorsiflexion to the maximum range with a 10-second hold, followed by plantarflexion with a 10-second hold and clockwise and counter-clockwise rotation 10 times each, constituted one set; five sets were prescribed hourly with 5-second rests between sets. Nurses routinely supervised ses-

sions and recorded performance in contemporaneous bedside nursing records. (4) Postoperative days 4–7: The pathway generally transitioned to oral nonsteroidal anti-inflammatory drug (NSAID)-based analgesia, with additional analgesics, including weak opioids, used when clinically required. Specific drugs, doses, and routes of administration varied according to individual physician orders and were not analyzed as a uniform regimen. APE intensity was prescribed to increase to 10 sets per hour and at least 90 sets per day; sitting, standing, and weight-bearing progression was individualized according to clinical condition and fixation stability. These figures represent the standardized pathway prescription and do not indicate independently verified completion of every prescribed set.

(5) Post-discharge follow-up period (6 weeks to 3 months): Patients were provided with an illustrated APE manual, with a prescribed gradual increase to 120–150 sets per day. Functional gait training was planned after 6 weeks according to progressive weight-bearing principles, and crutch discontinuation was individualized. Strenuous contact sports were avoided for 3 months, and activities of daily living were resumed gradually. Post-discharge implementation was extracted from routine follow-up documentation when available; objective real-time monitoring of home adherence was not performed in this retrospective study.

Operative Procedure and Postoperative Restrictions

All included patients underwent ORIF as part of routine orthopedic care. The present study did not assign an anesthesia technique, surgical approach, fixation construct, postoperative immobilization method, or weight-bearing schedule. These decisions were individualized by the treating anesthesiology and orthopedic teams according to fracture morphology, soft-tissue condition, fixation stability, and clinical status. Implant selection and fixation of the medial, lateral, and posterior malleoli therefore followed patient-specific operative judgment rather than a study-mandated protocol. Weight-bearing progression likewise required treating-surgeon assessment and was not determined solely by pathway group. The retrospective analytic dataset did not contain sufficiently standardized patient-level details on anesthesia, surgical approach, fixation construct, or immobilization to permit reliable between-group comparisons; these factors may consequently represent unmeasured confounders.

Outcome Measures

Primary outcome measure: American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale (total score: 0–100 points), comprising three dimensions—pain (40 points), function (45 points), and alignment (15 points). Assessments were conducted preoperatively and at 1 week, 1 month, and 3 months postoperatively; higher scores indicate better recovery. The AOFAS Ankle-Hindfoot Scale has demonstrated acceptable reliability, validity, and responsiveness in patients with ankle fractures [9]. Visual Analog Scale (VAS): A standard 10-cm scale was used, where 0 points indicate no pain and 10 points indicate the most severe pain; assessments were performed preoperatively and at 1 week, 1 month, and 3 months postoperatively. The VAS is widely used to quantify pain intensity and has demonstrated acceptable measurement reliability [10].

Secondary outcome measures included operative time (minutes), time to first out-of-bed mobilization (hours), length of hospital stay (days), total hospitalization costs (CNY), patient satisfaction, and incidence of lower-extremity deep vein thrombosis (DVT). Patient satisfaction was abstracted from the routine binary "satisfied/dissatisfied" field in discharge nursing documentation and was assessed at discharge; no validated multi-item satisfaction instrument was used. DVT was defined according to the final diagnostic conclusion in the routine lower-extremity venous Doppler ultrasonography report obtained on postoperative day 7; a report documenting lower-extremity venous thrombosis was counted as DVT. Day-7 ultrasound reports were available for all 84 patients (100%). The retrospective analytic records did not consistently document whether screening involved the affected limb alone or both lower limbs, the identity or number of examiners, or the explicit sonographic diagnostic criteria; these details therefore could not be reconstructed reliably. Total hospitalization costs were extracted from the itemized hospital billing records for the index admission, covering the period from admission to discharge. These costs included charges for surgery and anesthesia, internal-fixation implants and other consumable materials, medications, laboratory and imaging examinations, bed and nursing care, and inpatient rehabilitation. Post-discharge expenses, outpatient follow-up costs, patient-borne indirect costs, and productivity losses were not included; therefore, this variable represents direct inpatient hospital charges rather than a formal economic or cost-effectiveness evaluation.

Statistical Methods

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and Python version 3.12 (Python Software Foundation, Wilmington, DE, USA). The normality of each continuous variable was assessed using the Shapiro–Wilk test together with visual inspection of quantile–quantile (Q–Q) plots, and homogeneity of variance was assessed using Levene's test. Continuous variables judged to be approximately normally distributed are expressed as mean ± standard deviation (mean ± SD), whereas skewed continuous variables were presented as median and interquartile range (IQR). Between-group comparisons were performed using independent-samples *t*-tests, with Welch's correction used when the homogeneity-of-variance assumption was not met; categorical data are expressed as frequencies (%) and were analyzed using the chi-square (χ^2) test or Fisher's exact test. For continuous perioperative outcomes, unadjusted

between-group mean differences and 95% confidence intervals (CIs) were calculated; for binary outcomes, unadjusted odds ratios (ORs) and 95% CIs were calculated from 2 × 2 tables. Longitudinal AOFAS and VAS scores were analyzed using mixed-design repeated-measures analysis of variance (RM-ANOVA). Mauchly's test was used to assess sphericity. When the sphericity assumption was violated, the Greenhouse-Geisser correction was applied, and the corrected numerator and denominator degrees of freedom (original df multiplied by ε) and corrected p values were reported; the F statistics and partial eta-squared values were unchanged by this correction. Following a significant time-by-group interaction, four prespecified between-group comparisons—preoperatively and at 1 week, 1 month, and 3 months postoperatively—were performed using independent-samples t-tests or Mann–Whitney U test. These p values were Bonferroni-adjusted by multiplying the unadjusted value by four and were capped at 1.000. Effect sizes for independent-samples comparisons were reported as Cohen's d, calculated using the pooled standard deviation; values of approximately 0.2, 0.5, and 0.8 were interpreted as small, medium, and large effects, respectively. Partial eta-squared (η^2p) was reported for RM-ANOVA effects. The reported t statistics, p values, Cohen's d values, partial η^2 values, and RM-ANOVA parameters were rechecked for internal consistency using the unrounded analytic values; means and SDs displayed in the tables were rounded for presentation. No multivariable or propensity score model was performed; therefore, all reported between-group estimates are explicitly presented as unadjusted associations and should not be interpreted as causal effects. All tests were two-tailed, and $p < 0.05$ was considered statistically significant after the specified correction.

Results

Comparison of Baseline Data

The consecutive database search identified 84 patients with trimalleolar fractures who met all eligibility criteria; none were excluded after eligibility assessment. All 84 patients were included in the analytic cohort, comprising 43 in the routine-management group and 41 in the intensive-pathway group. Complete medical records and documented 3-month follow-up were available for all included cases (84/84, 100%), with no recorded loss to follow-up. The participant-selection process is shown in Fig. 1. No statistically significant differences were observed in age, sex, body mass index (BMI), fracture side, mechanism of injury, time from injury to surgery, ASA grade, hypertension, or current smoking (all $p > 0.05$). However, the absence of statistically significant differences does not establish covariate balance, and residual or unmeasured confounding cannot be excluded. Details are shown in Table 1. Day-7 Doppler screening was complete in all 84 patients (100%).

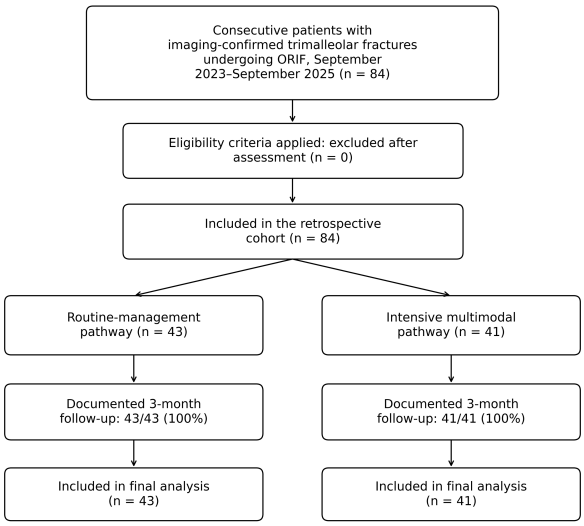


Fig. 1. Participant flow diagram. ORIF, open reduction and internal fixation.

Perioperative Clinical Outcomes

In the unadjusted comparisons, receipt of the intensive multimodal perioperative management pathway was associated with earlier first out-of-bed mobilization (mean difference [MD], −22.80 h; 95% confidence interval [CI], −26.48 to −19.12), shorter hospitalization (MD, −3.30 days; 95% CI, −4.14 to −2.46), and lower hospitalization costs (MD, −13,114 CNY (1 USD = 7.1429 CNY); 95% CI, −14,979 to −11,249). Patient satisfaction, assessed at discharge using the routine binary record, was higher in the intensive-pathway group (OR, 5.16; 95% CI, 1.04–25.56). DVT occurred in 8/43 patients (18.6%) in the routine-management group and 3/41 patients (7.3%) in the intensive-pathway group; the difference was not statistically significant (OR, 0.35; 95% CI, 0.08–1.41). Because the analytic dataset did not permit reliable classification of DVT events by symptom status or venous segment, no DVT composition percentages are reported. These estimates are unadjusted and may have been influenced by non-random pathway allocation, confounding by indication, and calendar-time changes in perioperative practice (Tables 2,3).

AOFAS Ankle-Hindfoot Scale Score

In the unadjusted longitudinal analysis, AOFAS scores were higher in the intensive-pathway group at all postoperative time points (Bonferroni-adjusted $p \leq 0.016$). Mixed-design RM-ANOVA showed significant group and time effects and a significant time-by-group interaction, indicating different observed score trajectories between the groups. After Greenhouse-Geisser correction, the F statistics were $F(2.72, 222.88) = 516.23$ for the time effect and $F(2.72, 222.88) = 15.62$ for the time-by-group interaction (both corrected $p < 0.001$). Because pathway allocation was nonrandom and no covariate-adjusted longitudinal model was performed, these differences cannot be interpreted as causal effects of the intensive pathway (Tables 4,5).

Table 1. Comparison of baseline data between the routine-management and intensive-pathway groups.

Variable	Routine-management group (n = 43)	Intensive-pathway group (n = 41)	Statistic	*p*-value
Age (years), mean ± SD	43.8 ± 9.6	44.0 ± 10.7	$t = -0.090$	0.928
Sex (male/female)	22/21	23/18	$\chi^2 = 0.205$	0.650
BMI (kg/m^2), mean ± SD	25.8 ± 2.5	26.9 ± 3.1	$t = -1.780$	0.079
Fracture side (left/right), n	26/17	21/20	$\chi^2 = 0.728$	0.394
Mechanism of injury (fall/traffic/sports), n	22/15/6	21/11/9	$\chi^2 = 1.192$	0.551
Time from injury to surgery (days), mean ± SD	5.1 ± 1.6	5.2 ± 1.4	$t = -0.343$	0.732
ASA grade (I/II), n	24/19	26/15	$\chi^2 = 0.503$	0.478
Hypertension, n (%)	11 (25.6%)	16 (39.0%)	$\chi^2 = 1.739$	0.187
Current smoking, n (%)	7 (16.3%)	6 (14.6%)	$\chi^2 = 0.043$	0.835

Note: Independent-samples *t*-tests were used for continuous variables; chi-square tests were used for categorical variables. BMI, body mass index; ASA, American Society of Anesthesiologists; SD, standard deviation.

Table 2. Comparison of perioperative clinical outcomes between the routine-management and intensive-pathway groups (continuous outcomes).

Outcome	Routine-management group (n = 43), Mean ± SD	Intensive-pathway group (n = 41), Mean ± SD	*t*-value	*p*-value	Cohen's d
Operation duration (min)	84.7 ± 14.4	83.1 ± 8.7	$t = 0.603$	0.548	0.132
Time to first out-of-bed activity (h)	51.7 ± 9.6	28.9 ± 7.2	$t = 12.264$	<0.001	2.677
Length of hospital stay (days)	10.3 ± 2.3	7.0 ± 1.5	$t = 7.661$	<0.001	1.672
Total hospitalization costs (CNY)	44,767 ± 4184	31,653 ± 4399	$t = 14.004$	<0.001	3.057

Note: Table 2 presents continuous outcomes as Mean ± SD and was analyzed using independent-samples *t*-tests. Unadjusted mean differences with 95% confidence intervals are reported in the accompanying text. For reference, the 2025 annual average exchange rate was 1 USD = 7.1429 CNY, as reported by the National Bureau of Statistics of China.

Table 3. Comparison of perioperative clinical outcomes between the routine-management and intensive-pathway groups (categorical outcomes).

Outcome	Routine-management group (n = 43), n (%)	Intensive-pathway group (n = 41), n (%)	Statistical test	*p*-value
Patient satisfaction	34 (79.1%)	39 (95.1%)	$\chi^2 = 4.752$	0.029
DVT incidence	8 (18.6%)	3 (7.3%)	$\chi^2 = 2.350$	0.125

Table 3 presents categorical outcomes as n (%) and was analyzed using the chi-squared test Unadjusted odds ratios with 95% confidence intervals are reported in the accompanying text. DVT, deep vein thrombosis.

Table 4. Comparison of AOFAS Ankle-Hindfoot Scale scores between the routine-management and intensive-pathway groups (mean ± SD, points).

Assessment time point	Routine-management group (n = 43)	Intensive-pathway group (n = 41)	*t*-value	Adjusted *p*†	Cohen's d
Preoperative	41.5 ± 9.2	42.1 ± 5.4	–0.358	1.000	0.078
1 week postoperatively	50.7 ± 7.1	62.1 ± 7.4	–7.216	<0.001	1.575
1 month postoperatively	63.1 ± 8.3	77.9 ± 8.6	–8.021	<0.001	1.751
3 months postoperatively	83.1 ± 7.6	87.4 ± 5.6	–2.955	0.016	0.645

† *p* values in the upper section are Bonferroni-adjusted for four prespecified comparisons; AOFAS, the American Orthopaedic Foot and Ankle Society.

Table 5. Mixed-design repeated measures ANOVA results of AOFAS scores in two groups.

Source of variation	F-value	df_1	df_2	*p*-value	Partial η^2 (η^2p)
Between-group effect (Group)	89.95	1	82	<0.001	0.523
Main effect of time (Time)	516.23	2.72	222.88	<0.001	0.863
Time × Group interaction (Interaction)	15.62	2.72	222.88	<0.001	0.160

ANOVA, analysis of variance; df, degrees of freedom.

VAS Pain Scores

In the unadjusted longitudinal analysis, VAS scores were lower in the intensive-pathway group at all postoperative time points (all Bonferroni-adjusted $p < 0.001$). Mixed-design RM-ANOVA showed significant group and time effects and a significant time-by-group interaction, indicat-

Table 6. Comparison of VAS pain scores between the routine-management and intensive-pathway groups (points).

Assessment time point	Routine-management group (n = 43)	Intensive-pathway group (n = 41)	Statistic (t/U)	Adjusted p†	Cohen's d/Effect size
Preoperative	6.7 ± 1.1	7.1 ± 1.4	–1.397	0.665	0.305
1 week postoperatively	4.8 ± 1.0	3.9 ± 0.9	4.239	<0.001	0.925
1 month postoperatively	3.2 ± 1.0	1.3 ± 0.7	9.926	<0.001	2.167
3 months postoperatively	2.0 (1.0, 2.0)	1.0 (0.0, 1.0)	276.000	<0.001	0.687

† p values in the upper section are Bonferroni-adjusted for four prespecified comparisons. VAS, Visual Analog Scale. Effect sizes are Cohen's d for the first three assessments and the absolute rank-biserial correlation for the 3-month assessment.

Table 7. Mixed-design repeated measures ANOVA results of VAS scores in two groups.

Source of variation	F-value	df_1	df_2	p-value	Partial eta squared (η_p^2)
Between-group effect (Group)	74.34	1	82	<0.001	0.476
Main effect of time (Time)	534.01	2.30	188.93	<0.001	0.867
Time × Group interaction (Interaction)	18.23	2.30	188.93	<0.001	0.182

ing different observed pain-score trajectories between the groups. After Greenhouse-Geisser correction, the F statistics were F(2.30, 188.93) = 534.01 for the time effect and F(2.30, 188.93) = 18.23 for the time-by-group interaction (both corrected $p < 0.001$). These results remain subject to selection bias and residual confounding and do not establish that the pathway caused the observed differences (Tables 6,7).

Discussion

This single-center retrospective cohort study found that receipt of an intensive multimodal perioperative management bundle was associated with earlier mobilization, shorter hospitalization, lower hospitalization costs, higher patient satisfaction, and more favorable short-term AOFAS and VAS trajectories after ORIF for trimalleolar fractures. The experimental group differed from the control group in multiple simultaneously delivered components, including preoperative optimization, quantified and supervised APE, multimodal analgesia, drain and catheter policies, early mobilization, and post-discharge follow-up. Accordingly, the observed differences should be interpreted as associations with the integrated bundle and cannot be assigned to preoperative optimization, APE, or any other individual component. Moreover, pathway allocation was nonrandom, and the unadjusted effect estimates were large; selection bias, confounding by indication, clinician- or patient-related pathway selection, and secular changes during the study period may therefore have contributed to the findings.

Interpretation of Early Recovery Outcomes

The intensive-pathway group mobilized 22.80 hours earlier on average than the routine-management group (MD, −22.80 h; 95% CI, −26.48 to −19.12). Previous studies of ankle fractures evaluating structured perioperative or ERAS pathways have reported shorter hospitalization and more favorable early recovery outcomes [11,12], while the broader perioperative literature recognizes early mobilization as an important component of multimodal recovery pathways [13]. However, randomized evidence on early weight bearing after operative treatment of ankle fractures and systematic-review evidence on ankle-fracture rehabilitation indicate that the timing of weight bearing should be interpreted in relation to fixation stability, patient selection, and heterogeneity in rehabilitation protocols [14,15]. These studies provide clinical context but do not validate the magnitude of the present unadjusted bundle-level association. The current study did not assess changes in nutritional status, psychological readiness, inflammatory markers, muscle preservation, bone healing, or other candidate mechanisms; therefore, the pathway through which the bundle may have been associated with earlier mobilization cannot be determined.

The routine-management group also received basic APE guidance, whereas the intensive-pathway group received quantified prescriptions, bedside supervision, structured progression, and post-discharge follow-up together with several other management components. Venous hemodynamics and objectively measured exercise adherence were not evaluated. Accordingly, the present data cannot determine whether APE independently contributed to functional recovery, pain reduction, or DVT prevention, and the large observed difference may also reflect patient selection, clinical decision-making, or calendar-period effects.

Interpretation of the Clinical Significance of Functional Scores

The unadjusted between-group mean differences in AOFAS scores at 1 week, 1 month, and 3 months postoperatively were 11.4, 14.8, and 4.3 points, respectively; these values represent between-group differences at each time point rather than within-group changes from baseline. The differences were numerically larger at 1 week and 1 month postoperatively, whereas the 3-month difference was smaller. Published studies examining physical therapy timing and early weight bearing also illustrate that postoperative re-

covery trajectories may vary with age, fracture pattern, fixation stability, and rehabilitation timing [16,17]. Because no population-specific minimal clinically important difference was prespecified or validated for this cohort, the 3-month difference of 4.3 points—and the other between-group differences—should not automatically be interpreted as clinically important. Differences in study populations, intervention components, follow-up schedules, and analytical methods also preclude valid claims of superiority over other rehabilitation or ERAS approaches.

The time-by-group interactions for AOFAS and VAS were statistically significant, indicating different observed score trajectories over time. These statistical interactions are descriptive and do not identify the biological or clinical mechanisms underlying the differences. They also cannot distinguish a pathway-related association from selection bias, confounding by indication, or secular changes in care.

Pain Management as One Component of the Multimodal Bundle

Pain management was one component of the intensive multimodal bundle. Contemporary reviews of foot and ankle surgery emphasize that multimodal analgesia and regional or systemic techniques should be individualized rather than applied as a single uniform regimen [18]. In the present cohort, PCA was used when prescribed, and subsequent analgesic selection and adjustment followed individual physician orders. Because specific agents, doses, routes of administration, and cumulative exposure were not analyzed between groups, the observed VAS differences cannot be attributed to a particular analgesic technique or drug. At 1 month postoperatively, the mean VAS score was 1.3 in the intensive-pathway group and 3.2 in the routine-management group, but this difference was observed alongside all other components of the bundle and remains an unadjusted association.

The intensive-pathway group had a shorter hospital stay (MD, −3.30 days; 95% CI, −4.14 to −2.46) and lower hospitalization costs (MD, −13,114 CNY; 95% CI, −14,979 to −11,249). These findings describe unadjusted differences in hospitalization-related outcomes and should not be interpreted as evidence that the pathway caused the reductions. The cost outcomes comprised itemized direct charges incurred during the index hospitalization and did not include post-discharge expenses, indirect costs, health outcomes expressed as quality-adjusted life-years, or incremental cost-effectiveness measures. No formal cost-effectiveness, cost-utility, or budget-impact analysis was conducted. The relatively narrow dispersion should be interpreted within the context of a single institution and a standardized ORIF pathway, not as evidence of generalizable economic benefit.

Reflections on DVT Prevention Strategies

DVT occurred in 8/43 patients (18.6%) in the routine-management group and 3/41 patients (7.3%) in the intensive-pathway group. Physiological evidence identifies the lower-leg muscle pump as an important contributor to venous return [19], and a meta-analysis of randomized trials reported that postoperative APE may reduce DVT and improve venous hemodynamic measures after lower-limb orthopedic surgery [20]. Nevertheless, the between-group difference in the present study was not statistically significant, and the 95% CI was wide (OR, 0.35; 95% CI, 0.08–1.41). Because the available analytic records did not contain standardized event-level information on symptom status or venous segment, the proportions of DVT composition are neither presented nor interpreted. Moreover, APE was only one component of the management bundle and pathway allocation was non-random; therefore, the lower observed proportion cannot be attributed to APE, the no-drain strategy, or any other individual measure. Larger prospective studies using standardized, longitudinal ultrasound screening are required.

Limitations

This study has several limitations. First, pathway allocation was non-random, and the specific rationale for selecting one pathway over the other was not uniformly documented in the retrospective records. Pathway assignment may have been influenced by clinician preference, patient characteristics, pathway availability, operational factors, and calendar period. Selection bias, confounding by indication, and secular changes in perioperative care may have influenced the observed associations between the management pathway and short-term recovery outcomes. The absence of statistically significant baseline differences does not exclude clinically meaningful imbalance or unmeasured confounding. No multivariable or propensity-score adjustment was performed; accordingly, all effect estimates remain unadjusted and residual or unmeasured confounding cannot be excluded. The specific formulations, doses, and duration of nutritional supplementation were not consistently available in the retrospective records, limiting assessment of the contribution of nutritional support to the observed outcomes. Second, although the intensive pathway was a standardized routine-care pathway and its implementation was recorded contemporaneously, exposure and adherence were determined retrospectively from clinical documentation. Completion of every prescribed APE session could not be independently verified, documentation intensity may have differed between groups, and post-discharge adherence was not objectively monitored; information bias and exposure misclassification therefore remain possible. Third, the single-center setting may limit generalizability of the findings. Fourth, the 3-month follow-up did not capture long-term functional outcomes, including post-traumatic osteoarthritis. Consequently, the observed associations cannot establish causality. Fifth, the one-day preoperative optimization should not be interpreted as conventional multi-week prehabilitation. Sixth, because multiple perioperative components were implemented concur-

rently, the study could evaluate only the integrated bundle and could not isolate the independent contribution of preoperative optimization, APE, analgesia, drain or catheter policies, early mobilization, or follow-up. Seventh, DVT was assessed only once using routine Doppler ultrasound reports on postoperative day 7. Although screening was complete (84/84), laterality, examiner information, explicit sonographic criteria, and standardized event-level classification by symptom status or venous segment were not consistently available; later or post-discharge events may also have been missed because the screening time approximated discharge in the intensive-pathway group (mean length of stay, 7.0 days). Eighth, the apparent 100% 3-month follow-up reflects complete documentation within the identified analytic cohort rather than prospective retention. Although consecutive case identification was used, patients whose treatment or follow-up was not fully captured in the electronic databases could have been missed, and selection or attrition bias in the wider source population cannot be excluded. Ninth, routine-management records did not consistently document the initiation time, repetitions per session, daily frequency, supervision, or completion of basic APE, so the actual between-group difference in delivered exercise dose could not be quantified. Tenth, patient-level details on anesthesia technique, surgical approach, fixation construct, postoperative immobilization, weight-bearing restrictions, and drug-level analgesic exposure were not available in a sufficiently standardized form for between-group comparison or adjustment; these factors may therefore have contributed to residual confounding. Eleventh, patient satisfaction was derived from a routine, nonvalidated binary discharge item rather than a validated multi-item instrument, which may have introduced measurement and ceiling bias.

Conclusions

In this single-center retrospective cohort, receipt of an intensive multimodal perioperative management bundle was associated with earlier mobilization, shorter hospitalization, lower hospitalization costs, and more favorable short-term functional and pain outcomes after ORIF for trimalleolar fractures. These findings apply to the integrated bundle and do not establish the efficacy of preoperative optimization, ankle-pump exercise, or any other individual component. Because pathway allocation was non-random, the analyses were unadjusted, and residual confounding could not be excluded, these findings should not be interpreted as definitive causal effects. This study did not establish cost-effectiveness and therefore does not support recommendations for broad clinical implementation; prospective controlled studies are required.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

MH designed the study, organized the team and supervised the whole research. YC contributed to the research design and data analysis. YZ and XZ provided routine ward-based rehabilitation care, instructed patients in ankle-pump exercises, extracted data from existing medical records, and reviewed routine follow-up records. HD contributed to the research design, guided the study, and managed journal submission. MH drafted the manuscript. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study protocol was approved by the Ethics Committee of Wuhan No.8 Hospital (Wuhan Anorectal Hospital) (Ethics Approval No.: HEC-PJ-20251022-001) and was conducted in accordance with the Declaration of Helsinki. Because this retrospective study used existing de-identified records and involved no additional research intervention, the requirement for written informed consent was waived by the Ethics Committee.

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Conflict of Interest

The authors declare no conflict of interest.

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