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Article

Development and Evaluation of a Dynamic, Precise Decompression-Hemostasis Strategy after Surgery *via* the Distal Radial Artery Approach Based on Multimodal Monitoring Indicators

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Abstract

Background: This study aimed to develop and assess a dynamic, precise decompression-hemostasis strategy based on multimodal monitoring indicators, and to investigate the effectiveness and safety of this strategy in hemostasis management after surgery *via* the distal radial artery approach. **Methods:** In this single-center prospective cohort study, 224 patients undergoing coronary angiography (CAG) or percutaneous coronary intervention (PCI) (January 2024 to June 2025) were consecutively assigned to a dynamic precise decompression group or a conventional compression group (n = 112 each). The dynamic strategy used individualized decompression guided by indicators such as activated clotting time (ACT) and perfusion index, whereas the control group followed conventional empirical fixed procedures. Hemostasis outcomes, patient comfort, and vascular complications were compared. Logistic regression identified risk factors for hemostasis failure, and a predictive model was constructed. **Results:** No significant differences were observed in initial hemostasis success, rebleeding, or hematoma rates ($p > 0.05$). The dynamic group showed significantly shorter compression time and higher first-attempt hemostat removal success ($p < 0.05$). Pain scores, local discomfort, and overall satisfaction were more favorable in the dynamic precise decompression group ($p < 0.05$). The 30-day distal radial artery occlusion rate was numerically lower in the dynamic precise decompression group, but the difference was not statistically significant ($p > 0.05$). ACT, body mass index (BMI), and sheath type were independent risk factors for hemostasis failure, while the dynamic strategy was independently associated with lower odds of hemostasis failure. The model showed acceptable discrimination, and exploratory subgroup analyses suggested possible heterogeneity according to ACT and BMI. **Conclusions:** Multimodal monitoring-guided dynamic decompression was associated with shorter compression time and more favorable comfort-related outcomes without an observed increase in bleeding complications. The 30-day distal radial artery occlusion (RAO) rate showed only a nonsignificant numerical trend toward reduction. These findings support further evaluation of this individualized hemostasis strategy in randomized controlled trials or externally validated studies.

Keywords: compression devices; distal radial access; hemostasis; monitoring; radial artery

1. Introduction

The radial artery approach has become the preferred approach for coronary angiography (CAG) or percutaneous coronary intervention (PCI), and its advantages of lower rates of bleeding complications, fewer vessel-related adverse events, and higher patient comfort have been demonstrated in multiple clinical studies [1,2]. Compared with the femoral artery approach, the radial artery approach not only reduces the risk of severe bleeding and death, but also shortens length of hospital stay and ameliorates overall patient prognosis, so it has been rapidly popularized worldwide [3]. With the continuous advance in technology recently, the distal radial artery approach has gradually attracted attention. Through puncture in the anatomical snuffbox *via* this approach, blood flow in the forearm radial artery trunk is preserved, theoretically reducing the risk of radial artery occlusion (RAO), and displaying potential advantages in patients undergoing repeated interventions [4]. Research suggests that the distal radial artery approach is comparable to the traditional radial artery approach in both safety and feasibility, and it may be superior in vascular protection. However, the distal radial artery has a shallower anatomical position, a smaller diameter and less surrounding soft tissue than the traditional radial artery, making its postoperative hemostasis management face higher technical requirements [5].

Nowadays, balloon hemostat has been widely used in clinical practice for compression hemostasis, and its simple operation and good controllability makes it become a common method of hemostasis after surgery *via* the radial artery approach [6]. However, staged decompression management of available hemostasis strategies rely on empirical fixed schedules, and a dynamic adjustment basis based on individual differences is lacking. Research suggests that excessive compression may lead to distal blood flow restriction, and raise the risk of vascular occlusion, tissue ischemia and even nerve damage, while premature or too rapid decompression may cause rebleeding or hematoma formation,

thus prolonging compression and affecting patient recovery [7,8]. Therefore, keeping distal artery patency while ensuring hemostasis safety has become a key difficulty in postoperative management of distal radial artery and an important issue to be solved urgently in current clinical practice [9].

Previous studies have mostly focused on optimization of compression time or improvement of hemostatic devices, such as adjusting compression duration or improving balloon structure, but paid little attention to dynamic decision-making mechanism during decompression [10,11]. In particular, significant individual differences exist in coagulation function, hemodynamic status and local tissue response in actual clinical practice, which, however, are difficult to be reflected in the existing fixed procedures. Besides, continuous evaluation methods for real-time changes during decompression are also lacking. In recent years, the concept of multimodal monitoring has gradually emerged in intensive care medicine and perioperative management, and dynamic assessment and precise intervention of patients can be achieved by integrating multi-source physiological information [12]. However, this concept has been rarely applied to the hemostasis management after surgery *via* the distal radial artery approach, relevant evidence is insufficient, and a systematic management strategy combining coagulation status, perfusion indicators and clinical manifestations is lacking.

In the above context, this study innovatively developed a dynamic precise decompression strategy based on multimodal monitoring indicators, which was used to assess and individually regulate the hemostasis process in real time by integrating biological indicators, perfusion indicators and clinical manifestations. This study intends to systematically assess the clinical value of this strategy in the hemostasis outcomes, patient comfort and vascular protection by prospective observation, and further investigate its applicability and underlying mechanism across different risk groups. The findings are expected to provide a more precise, adjustable and propagable clinical strategy for hemostasis management after surgery *via* the distal radial artery approach.

2. Materials and Methods

2.1 Study Design and Subjects

This single-center, prospective observational cohort study was conducted strictly following the STROBE statement for observational studies. Patients who successfully underwent CAG or PCI *via* the distal radial artery approach (anatomical snuffbox) in the Department of Cardiology of our hospital from January 2024 to June 2025 were enrolled.

Inclusion criteria were as follows: (1) patients aged ≥18 years old, (2) those who successfully underwent CAG or PCI *via* the distal radial artery approach, (3) those who received local compression hemostasis using balloon hemostat postoperatively, and (4) those with clear consciousness, and able to cooperate in postoperative multimodal monitoring (such as fingertip blood oxygen and waveform collection) and scheduled follow-up assessment.

Exclusion criteria included: (1) patients who failed in the distal radial artery puncture or required intraoperative crossover to other vascular approaches (e.g., traditional radial or femoral artery), (2) those with a history of severe coagulation dysfunction or severe active bleeding, (3) those with a history of distal/conventional RAO, arteriovenous fistula, or severe vascular malformation as assessed by preoperative ultrasound, or (4) those with extremely incomplete clinical or follow-up data, or who refused to participate in the study.

A total of 256 patients undergoing CAG or PCI *via* the distal radial artery approach were consecutively screened, of whom 32 were excluded due to no compliance with the inclusion criteria or refusal to participate. Finally, 224 patients were enrolled. Patients with extremely incomplete clinical data or unavailable follow-up data were excluded before the final analysis. Among the 224 patients included in the final cohort, key baseline variables, activated clotting time (ACT), hemostasis outcomes, and 24 h and 30 d follow-up ultrasound assessments were complete. Continuous perfusion index (PI) monitoring was applied only in the dynamic precise decompression group according to the study protocol; therefore, the absence of continuous PI data in the conventional compression group was considered a design feature rather than missing data, no statistical imputation was performed. The study protocol was strictly reviewed and approved by the Medical Ethics Committee of our Hospital (approval no. 2024-03-067-K001). All enrolled patients were fully informed of the study and voluntarily signed written informed consent forms preoperatively.

2.2 Classification Methods and Intervention Strategies

All enrolled patients received perioperative antiplatelet therapy according to routine clinical practice. The antiplatelet regimen was determined according to the clinical indication and procedure type. Patients undergoing PCI received dual antiplatelet therapy with aspirin and a P2Y12 receptor inhibitor in the absence of contraindications.

In our center, distal radial artery puncture was routinely performed under real-time guidance using a high-frequency linear ultrasound probe (7–12 MHz) to improve puncture success and reduce vascular injury. After successful puncture, the same type of radial artery short sheath was used in all patients (10 cm, Terumo Radifocus Glidesheath, Japan). A 5F or 6F sheath was selected by the operator according to the complexity of coronary angiography or PCI, based on the American College of Cardiology/American Heart Association (ACC/AHA) lesion classification, and device requirements.

After sheath insertion, vasodilators, including nitroglycerin 200 μg and/or verapamil 2.5 mg, were slowly administered through the sheath to prevent radial artery

spasm. For anticoagulation, all patients received systemic anticoagulation with unfractionated heparin. Patients undergoing diagnostic CAG routinely received heparin at 50 U/kg, whereas those undergoing PCI received heparin at 70–100 U/kg. Intraoperative ACT was closely monitored.

In the conventional compression group, after initial balloon inflation, distal radial artery patency was routinely confirmed using a modified reverse Barbeau test, that is, by compressing the ulnar artery and observing the recovery of the oxygen saturation waveform of the puncture-side thumb. In the dynamic precise decompression group, patent hemostasis was assessed using the multimodal monitoring system adopted in this study, including continuous fingertip PI and volume pulse waveform monitoring. This approach was used to monitor and maintain distal vascular patency throughout the compression process while achieving minimal effective compression.

According to the clinical hemostasis management strategy determined by the interventionalist's experience and the specific condition of the patient, the patients were managed with either a dynamic precise decompression strategy or a conventional compression strategy, with 112 cases in each group. The same model of distal radial artery balloon hemostat (TR Band, Terumo, Japan) was used in both groups.

A conventional empirical hemostasis strategy was adopted in the conventional compression group. Specifically, after removal of the sheath catheter, the balloon was initially inflated with 12 mL of air until there was no active bleeding at the puncture site. Subsequently, staged decompression was performed according to the established schedule of the department. In general, balloon deflation was initiated at approximately 30 min postoperatively and repeated every 30 min, with 2 mL of air deflated each time. If bleeding or rebleeding occurred at the puncture site during decompression, 1–2 mL of air was refilled and the compression duration was extended accordingly.

Individualized decompression was implemented based on multimodal monitoring indicators in the dynamic precise decompression group, with the goal of achieving minimal effective compression while maintaining distal artery patency. After sheath removal, the balloon hemostat was initially inflated with 12 mL of air in the same manner as in the conventional group until no active bleeding was observed at the puncture site. The timing of the first decompression was guided primarily by baseline ACT. Patients with ACT <275 s underwent the first decompression assessment at approximately 60 min after sheath removal, whereas those with ACT ≥275 s underwent the first decompression assessment at approximately 90 min. Before each decompression step, local hemostatic status and distal perfusion were jointly evaluated.

At each decompression step, 2 mL of air was withdrawn when all of the following criteria were met: (1) no active oozing or rebleeding at the puncture site; (2) no progressive hematoma enlargement; (3) stable or increased PI compared with the previous assessment; and (4) no obvious flattening of the pulse waveform. Decompression was suspended when PI showed a clear decline from the previous measurement, when pulse waveform amplitude became attenuated or flattened, or when local oozing was suspected. If active oozing, rebleeding, or progressive local swelling occurred, 1–2 mL of air was immediately refilled, and compression was prolonged by 30 min before reassessment.

Through the dynamic adjustment described above, individualized decompression based on multimodal indicators could be achieved (Fig. 1).

2.3 Definition of Multimodal Monitoring Indicators and Implementation Protocol

This study introduced a multimodal monitoring framework to guide individualized hemostasis decision-making. The indicators were divided into two dimensions: static baseline assessment and dynamic real-time feedback. The corresponding operational criteria for decompression continuation, suspension, and air refilling were predefined to improve the reproducibility of the protocol. Specific definitions and implementation details are as follows.

Static predictive indicators: These indicators mainly included biological and physiological characteristics such as intraoperative ACT and body mass index (BMI). They were used as static baseline factors for risk stratification of the potential difficulty in hemostasis immediately after surgery, thereby determining the safe time window for initiating the first decompression. In the dynamic precise decompression group, patients with ACT <275 s were generally reassessed for the first decompression at approximately 60 min after sheath removal, whereas patients with ACT ≥275 s were reassessed at approximately 90 min after sheath removal. BMI was used as an additional baseline risk indicator because higher BMI may increase the difficulty of local compression force transmission. Such indicators were routinely collected in both groups and incorporated into the subsequent influencing factor analysis model.

Dynamic physical monitoring indicators: The PI and volume pulse wave signals of the thumb on the puncture side were continuously monitored using a pulse oximeter (Radical-7, Masimo). These indicators served as real-time objective measures of distal microcirculation and blood flow recovery. Notably, continuous PI monitoring in this study was specifically applied to the dynamic precise decompression group as the core quantitative basis for guiding titrated deflation procedures. PI and pulse waveform monitoring were performed continuously during the compression and decompression process. No fixed numerical PI threshold or automatic alarm cutoff was preset in this observational protocol, because no validated PI cutoff has been established for guiding distal radial artery decompression. Operators were instructed to interpret PI dynamically by comparing the current PI value and pulse waveform am-

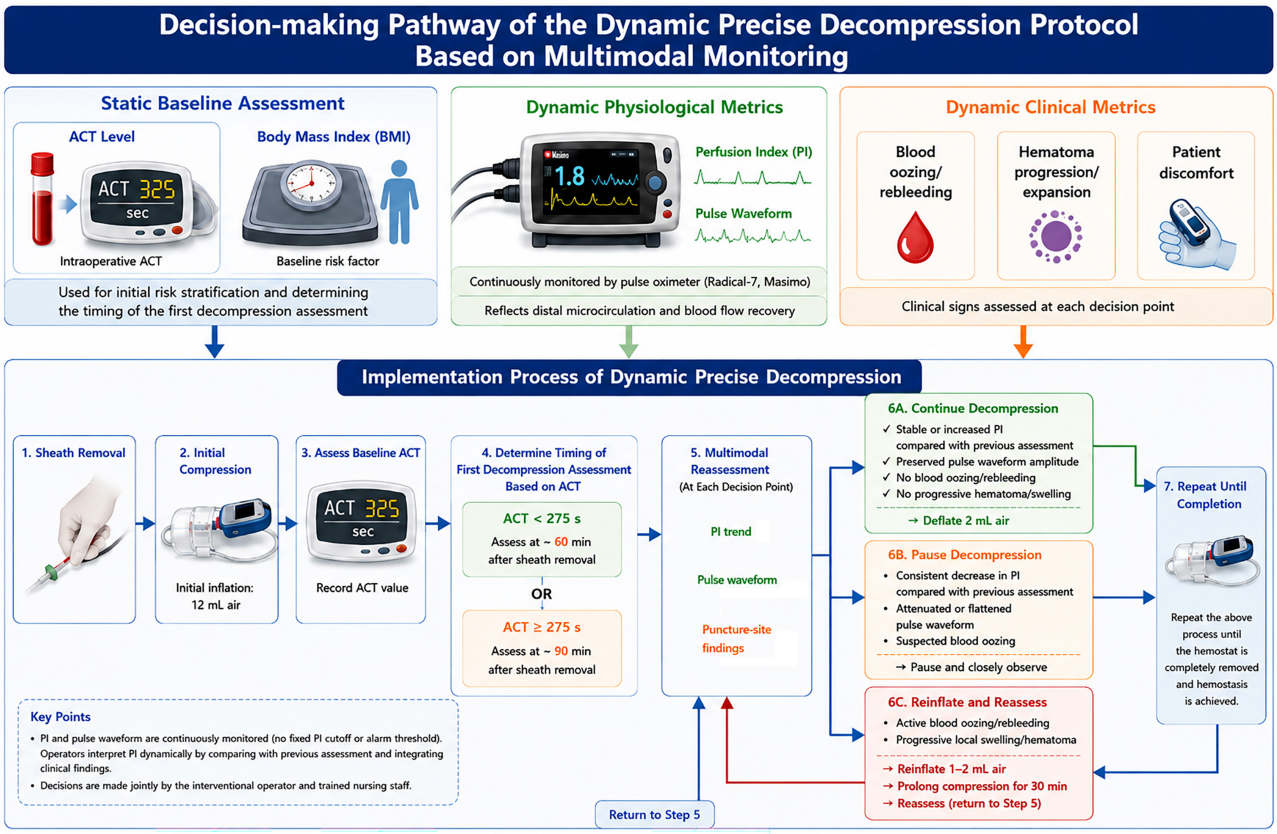

Fig. 1. Decision-making pathway of the dynamic precise decompression protocol based on multimodal monitoring. ACT and BMI were used as static baseline indicators for initial risk stratification. PI, pulse waveform, and local clinical signs were continuously monitored during compression and decompression. Further decompression was allowed when PI remained stable or increased, pulse waveform was preserved, and no blood oozing or hematoma progression was observed. Decompression was suspended when PI consistently decreased, pulse waveform became attenuated or flattened, or blood oozing was suspected. If active blood oozing, rebleeding, or progressive local swelling occurred, 1–2 mL of air was refilled, and compression was prolonged for 30 min before reassessment. ACT, activated clotting time; BMI, body mass index; PI, perfusion index.

plitude with the previous assessment and by integrating local puncture-site findings. Stable or increased PI with preserved pulse waveform amplitude was regarded as a signal allowing further decompression, whereas a consistent decrease in PI compared with the previous assessment or attenuation/flattening of the pulse waveform triggered temporary suspension of decompression.

Dynamic clinical manifestation indicators: These indicators acted as the intuitive clinical basis for judging the safety of decompression, including local bleeding at the puncture site, signs of subcutaneous hematoma expansion, skin temperature, and subjective patient discomfort. Active oozing, rebleeding, or progressive local swelling was regarded as a warning sign requiring immediate suspension of decompression and, when necessary, air refilling to restore local compression pressure.

Implementation process: In the dynamic precise decompression group, the multimodal indicators described above were integrated into a stepwise decision-making algorithm. At each decompression decision point, decompression was continued only when physical monitoring showed stable or rising PI with preserved pulse waveform amplitude and clinical assessment showed no active oozing, rebleeding, or hematoma enlargement. If PI showed an obvious decrease, pulse waveform amplitude became attenuated or flattened, or local oozing was suspected, decompression was suspended immediately and the puncture site was continuously observed. If active oozing, rebleeding, or progressive local swelling occurred, 1–2 mL of air was refilled, and compression was prolonged for an additional 30 min before reassessment. The decompression decision was made jointly by the interventional operator and trained nursing staff responsible for postprocedural compression monitoring. This process was repeated until complete removal of the hemostat. Through the closed loop of "static feature stratification + dynamic indicator feedback", individualized and titrated precise decompression was finally achieved.

2.4 Observation Measures and Outcome Definitions

The primary endpoint was total compression time, defined as the duration from sheath catheter removal to complete removal of the hemostat. This endpoint was selected because it directly reflected the efficiency of the decompression and hemostasis management strategy.

Secondary outcomes included other hemostasis-related outcomes, patient comfort outcomes, and vascular outcomes. Hemostasis-related secondary outcomes included initial hemostasis success rate, rebleeding rate, hematoma at the puncture site, and success rate of the first planned removal of the hemostat. Initial hemostasis success was defined as no active bleeding at the puncture point after initial balloon pressurization. Rebleeding was defined as bleeding requiring reintervention during decompression or removal. Prolonged compression was defined as additional compression beyond the prespecified decompression/removal schedule because of blood oozing, rebleeding, unstable hemostasis, or progressive local swelling; operationally, this required reinflation with 1–2 mL of air and extension of compression for at least 30 min before reassessment. Hematoma was classified as mild or moderate according to local swelling extent and clinical manifestations. Mild hematoma was defined as localized swelling or ecchymosis around the puncture site without progressive enlargement, severe pain, neurovascular compromise, or need for additional intervention. Moderate hematoma was defined as swelling or ecchymosis with obvious local tension or pain requiring prolonged compression or close observation, but without surgical intervention, transfusion, compartment syndrome, or persistent neurovascular impairment. Hemostasis failure was defined as the occurrence of rebleeding or the need for prolonged compression according to the predefined criteria. Patients who experienced both rebleeding and prolonged compression were counted only once in the composite endpoint of hemostasis failure.

Patient comfort outcomes included pain score, incidence of local discomfort, and overall satisfaction score. The Numeric Rating Scale (NRS, 0–10 points) was utilized for pain assessment after initial compression, at 1 h and 2 h postoperatively, and before removal of the hemostat. Local discomfort, including pressure, numbness, and swelling, was reported by patients and recorded by investigators. Overall satisfaction was assessed using a 5-point Likert scale, with 1 point indicating very dissatisfied and 5 points indicating very satisfied.

Vascular outcomes included the incidence of distal RAO and changes in hemodynamic parameters. RAO was assessed by color Doppler ultrasound (Philips EPIQ 7, linear array transducer frequency 7–12 MHz) at 24 h and 30 d postoperatively, with occlusion judged according to the disappearance or obvious weakening of blood flow signals. Hemodynamic parameters, including peak systolic velocity (PSV) and vascular diameter, were measured by experienced sonographers under standardized conditions. Given the exploratory nature of the secondary outcomes, these results were interpreted cautiously.

2.5 Follow-Up and Imaging Assessment

All patients underwent color Doppler ultrasonography of the distal radial artery at 24 h and 30 days postoperatively, which was performed by experienced sonographers. The main outcome metrics included vascular patency, blood flow signal, PSV, vascular diameter, and distal RAO. Clinical decisions regarding decompression were made according to the predefined protocol described above. Color Doppler ultrasound assessments were performed by experienced ultrasound operators who were blinded to group allocation. Because of the visible differences between the dynamic precise decompression strategy and conventional compression strategy, patients, interventional operators, and nursing staff responsible for compression and decompression management could not be blinded to group allocation. Pain scores, local discomfort, and satisfaction were collected using standardized scales and predefined assessment time points to reduce measurement variability. Data analysis was performed after completion of follow-up.

2.6 Statistical Analysis

SPSS 26.0 software (IBM, Armonk, NY, USA) was utilized for statistical analysis. All measurement data were assessed for normality by Shapiro-Wilk test before analysis. Continuous variables of normal distribution were described by mean ± standard deviation (SD), and compared between two groups by independent-samples *t*-test. Non-normally distributed data were described by median (quartile) and underwent Mann-Whitney U test. Count data were described by [n (%)] and underwent chi-square test. The inter-group and time effects of pain scores over time were assessed by repeated measures analysis of variance.

Univariable logistic regression analysis was performed to screen potential influencing factors, with hemostasis failure as a dependent variable. The variables with $p < 0.10$ were incorporated into the multiple logistic regression to calculate odds ratio (OR) and corresponding 95% confidence interval (CI). Multicollinearity among variables included in the multiple logistic regression model was assessed using the variance inflation factor (VIF) and tolerance. A predictive model was established based on the multiple logistic regression, and receiver operating characteristic (ROC) curves were generated to assess its discriminatory power, with the area under the curve (AUC) calculated. The optimal cutoff value was determined using Youden index. Internal validation of the predictive model was performed using bootstrap resampling with 1000 repetitions. In each bootstrap sample, the logistic regression model was refitted and its discriminatory performance was assessed. The optimism in the apparent AUC was estimated by comparing model performance in the bootstrap sample

Table 1. Comparison of baseline characteristics between the two groups.

Variable	Dynamic precise decompression group (n = 112)	Conventional compression group (n = 112)	t/χ^2	p
Age (year)	63.84 ± 9.12	64.27 ± 8.76	0.360	0.719
Male [n (%)]	78 (69.64)	81 (72.32)	0.195	0.659
BMI (kg/m^2)	24.63 ± 3.18	24.88 ± 3.05	0.600	0.549
Smoking history [n (%)]	46 (41.07)	49 (43.75)	0.165	0.685
Hypertension [n (%)]	68 (60.71)	72 (64.29)	0.305	0.581
Diabetes [n (%)]	32 (28.57)	35 (31.25)	0.192	0.662
Operation method (PCI) [n (%)]	52 (46.43)	55 (49.11)	0.161	0.688
Operation time (min)	42.56 ± 15.73	44.18 ± 16.02	0.764	0.446
Sheath catheter (6F) usage [n (%)]	74 (66.07)	77 (68.75)	0.183	0.669
ACT values (s)	278.45 ± 42.17	282.36 ± 45.02	0.671	0.503
Puncture times (times)	1.18 ± 0.45	1.22 ± 0.49	0.636	0.525

Data are presented as mean ± standard deviation (SD) or n (%), as appropriate. t, Student's t-test statistic; χ^2, Pearson's chi-squared statistic. ACT, activated clotting time; BMI, body mass index; PCI, percutaneous coronary intervention.

with that in the original dataset. The optimism-corrected AUC was then calculated by subtracting the estimated optimism from the apparent AUC. Model calibration was assessed using the Hosmer-Lemeshow goodness-of-fit test and a calibration plot comparing the predicted and observed probabilities of hemostasis failure. Subgroup analyses were stratified by ACT and BMI, and interaction tests were conducted to assess heterogeneity of interventions across different subgroups. $p < 0.05$ was deemed statistically significant.

3. Results

3.1 Comparison of Baseline Characteristics

No statistically significant differences were observed in demographics (age, sex composition, and BMI), past medical history (smoking history, hypertension, and diabetes) and perioperative related indicators (operation method, sheath catheter type, operation time, intraoperative ACT and puncture times) between the two groups ($p > 0.05$) (Table 1), suggesting generally balanced and comparable baseline characteristics between the two groups. To further reduce the impact of potential confounders, multivariable regression was used for adjustments in subsequent analyses.

3.2 Hemostasis-Related Outcomes

Initial hemostasis was effective in both groups. In terms of hemostasis safety, there were no statistically significant differences in the initial hemostasis success rate, rebleeding rate and hematoma at the puncture site between the dynamic precise decompression group and the conventional compression group ($p > 0.05$). Hemostasis was successful for rebleeding cases after compression, and there were no cases of surgical intervention. As to hemostasis efficiency, the dynamic precise decompression group was associated with a shorter median total compression time ($p < 0.001$) and a higher success rate of the first planned removal of hemostat than the conventional compression group ($p = 0.033$) (Table 2). To sum up, dynamic precise decompression was associated with more favorable hemostasis efficiency without an observed increase in bleeding-related complications.

3.3 Outcomes Related to Patient Comfort (Secondary Outcomes)

The NRS score decreased with time in both groups. Repeated measures analysis of variance revealed that time, intervention factors and their interaction had significant effects on pain scores ($p < 0.05$). There was no difference in initial NRS scores between the two groups ($p = 0.734$), but the NRS score in the dynamic precise decompression group was significantly lower than in the conventional compression group from 1 h postoperatively, which persisted until the removal of hemostat ($p < 0.01$). In addition, the incidence of local discomfort in the dynamic precise decompression group was significantly lower than in the conventional compression group ($p = 0.047$), primarily mild compression in the former and accompanied by persistent pain in the latter. Overall satisfaction scores were also significantly higher in the dynamic precise decompression group ($p < 0.001$) (Table 3). Collectively, dynamic precise decompression was associated with lower postoperative pain scores, less local discomfort, and higher overall satisfaction scores.

3.4 Vascular Outcomes and Complications (Secondary Outcomes)

No severe vascular complications occurred in either group. As for minor complications such as subcutaneous ecchymosis and transient hand numbness, their incidence had no statistically significant difference between the two groups ($p > 0.05$). During the follow-up, the incidence of RAO at 24 h and 30 days postoperatively in the dynamic precise decompression group was numerically lower than

Table 2. Comparison of hemostasis-related outcomes between the two groups.

Indicator	Dynamic precise decompression group (n = 112)	Conventional compression group (n = 112)	χ^2/Z	*p*
Initial hemostasis success rate [n (%)]	106 (94.64)	104 (92.86)	0.305	0.581
Rebleeding rate [n (%)]	7 (6.25)	10 (8.93)	0.573	0.449
Hematoma at the puncture site [n (%)]	9 (8.04)	13 (11.61)	0.806	0.369
Mild	7 (6.25)	10 (8.93)	-	-
Moderate	2 (1.79)	3 (2.68)	-	-
Total compression time (min) [median (IQR)]	125.0 (110.0, 150.0)	170.0 (150.0, 210.0)	9.479	<0.001
Success rate of the first planned removal of hemostat [n (%)]	102 (91.07)	91 (81.25)	4.530	0.033

Data are presented as median (interquartile range, IQR) or n (%), as appropriate. χ^2, Pearson's chi-squared statistic; Z, Mann-Whitney U test statistic.

Table 3. Comparison of outcomes related to patient comfort between the two groups.

Indicator	Dynamic precise decompression group (n = 112)	Conventional compression group (n = 112)	t/χ^2	*p*
Pain score (NRS)				
Initial	3.84 ± 1.12	3.79 ± 1.08	0.340	0.734
1 h postoperatively	3.02 ± 1.05	3.45 ± 1.12	2.964	0.003
2 h postoperatively	2.41 ± 0.96	3.12 ± 1.03	5.337	<0.001
Before the removal of hemostat	1.76 ± 0.82	2.68 ± 0.94	7.805	<0.001
Incidence of local discomfort [n (%)]	17 (15.17)	29 (25.89)	3.939	0.047
Overall satisfaction (point)	4.32 ± 0.61	3.88 ± 0.74	4.856	<0.001

Data are presented as mean ± standard deviation (SD) or n (%), as appropriate. *t*, Student's *t*-test statistic; χ^2, Pearson's chi-squared statistic. NRS, Numeric Rating Scale.

Table 4. Comparison of vascular outcomes and complications between the two groups.

Indicator	Dynamic precise decompression group (n = 112)	Conventional compression group (n = 112)	t/χ^2	*p*
Minor vascular complications [n (%)]				
Subcutaneous ecchymosis	11 (9.82)	15 (13.39)	0.696	0.404
Transient hand numbness	8 (7.14)	12 (10.71)	0.878	0.349
RAO [n (%)]				
24 h postoperatively	4 (3.57)	9 (8.04)	2.042	0.153
30 d postoperatively	3 (2.68)	8 (7.14)	2.390	0.122
Hemodynamic indicators (24 h postoperatively)				
PSV (cm/s)	42.36 ± 9.18	38.12 ± 8.75	3.538	<0.001
Vascular diameter (mm)	2.21 ± 0.34	2.05 ± 0.31	3.680	<0.001

Data are presented as mean ± standard deviation (SD) or n (%), as appropriate. *t*, Student's *t*-test statistic; χ^2, Pearson's chi-squared statistic. RAO, radial artery occlusion; PSV, peak systolic velocity.

in the conventional compression group, but the difference had no statistical significance ($p > 0.05$). Ultrasound evaluation at 24 h postoperatively showed that the PSV and vascular diameter of the distal radial artery were significantly higher in the dynamic precise decompression group than in the conventional compression group ($p < 0.001$) (Table 4). This suggests that dynamic precise decompression was associated with more favorable early hemodynamic status without an observed increase in vascular complications.

3.5 Results of Logistic Regression of Factors Associated With Hemostasis Failure

Hemostasis failure occurred in 31 patients, including 10 patients in the dynamic precise decompression group and 21 patients in the conventional compression group. Logistic regression analysis was performed to analyze the potential clinical factors, with hemostasis failure as a dependent variable. The results showed that BMI, intraoperative ACT values and sheath catheter type (6F) were associated with hemostasis failure ($p < 0.10$), while age, sex, hypertension,

Table 5. Univariable and multivariable logistic regression analyses of factors associated with hemostasis failure.

Variable	Univariable OR (95% CI)	*p*	Multivariable OR (95% CI)	*p*
Age (for each additional year)	1.02 (0.99–1.05)	0.118	-	-
Male	0.91 (0.50–1.66)	0.758	-	-
BMI (kg/m^2)	1.10 (1.03–1.18)	0.006	1.08 (1.01–1.16)	0.028
Hypertension	1.21 (0.68–2.17)	0.517	-	-
Diabetes	1.54 (0.83–2.85)	0.167	-	-
Operation method (PCI)	1.18 (0.66–2.12)	0.579	-	-
ACT (for every 10 s increase)	1.18 (1.08–1.29)	<0.001	1.22 (1.10–1.34)	0.003
6F sheath catheter	1.92 (1.06–3.47)	0.032	1.87 (1.01–3.45)	0.046
Dynamic precise decompression	0.58 (0.33–1.01)	0.053	0.52 (0.28–0.96)	0.037

BMI, body mass index; ACT, activated clotting time; OR, odds ratio; CI, confidence interval.

diabetes and operation method (CAG/PCI) were not significantly associated with hemostasis failure ($p > 0.10$) (Table 5).

The variables with $p < 0.10$ in the logistic regression were incorporated into the multiple logistic regression. Before multivariable logistic regression, multicollinearity among BMI, ACT, 6F sheath catheter use and dynamic precise decompression was assessed using variance inflation factor values. All VIF values <5, indicating no significant multicollinearity among the variables included in the final model. The results revealed that high ACT values (OR = 1.22, 95% CI: 1.10–1.34, $p = 0.003$), increased BMI (OR = 1.08, 95% CI: 1.01–1.16, $p = 0.028$) and use of 6F sheath catheter (OR = 1.87, 95% CI: 1.01–3.45, $p = 0.046$) were independently associated with an increased risk of hemostasis failure, whereas dynamic precise decompression was associated with lower odds (OR = 0.52, 95% CI: 0.28–0.96, $p = 0.037$).

3.6 Establishment and Evaluation of Predictive Model

A predictive model for the risk of hemostasis failure was established based on independent predictors screened by the multiple logistic regression analysis. The final logistic regression equation was as follows: logit(P) = –9.41 + 0.077 × BMI + 0.199 × ACT10 + 0.626 × 6F sheath catheter – 0.654 × dynamic precise decompression. It was assessed for comprehensive discriminatory power using ROC curve (Fig. 2). The results showed that the AUC of this model was 0.82 (95% CI: 0.75–0.89), suggesting acceptable preliminary discriminatory performance for the risk of distal radial artery hemostasis failure. As determined by the Youden index, the sensitivity and specificity of the model at the optimal cutoff value were 77.00% and 75.00%, respectively. The positive predictive value and negative predictive value at this cutoff were 33.3% and 95.4%, respectively. The relatively high negative predictive value suggested that the model may be useful for identifying patients at low risk of hemostasis failure, whereas the modest positive predictive value should be interpreted in the context of the relatively low incidence of hemostasis failure in this cohort. The analysis of clinical parameters suggested that the ACT value of about 275 s could serve as the optimal cutoff value for predicting hemostasis failure, which possessed certain clinical reference significance. To assess the potential optimism of the model, internal validation was performed using 1,000 bootstrap resamples. The estimated optimism was 0.03, and the optimism-corrected AUC was 0.79, suggesting that the model retained preliminary discriminatory performance after correction for optimism, although model performance estimates may still be optimistic because of the limited number of outcome events.

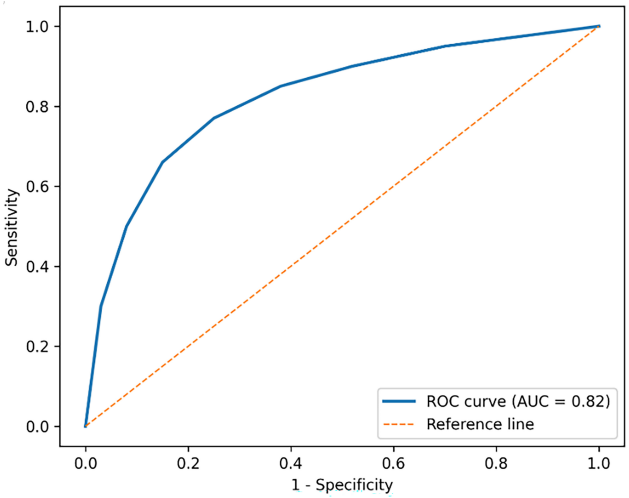

Fig. 2. ROC curve analysis results of predictive model for risk of hemostasis failure based on multiple logistic regression. ROC, receiver operating characteristic.

The calibration performance of the predictive model was further assessed using the Hosmer-Lemeshow goodness-of-fit test and a calibration curve. The Hosmer-Lemeshow test showed no statistically significant difference between the predicted and observed probabilities of hemostasis failure ($\chi^2 = 7.42$, df = 8, $p = 0.492$), indicating good model fit. The calibration curve also showed good agreement between the predicted probability and the observed probability of hemostasis failure, with the

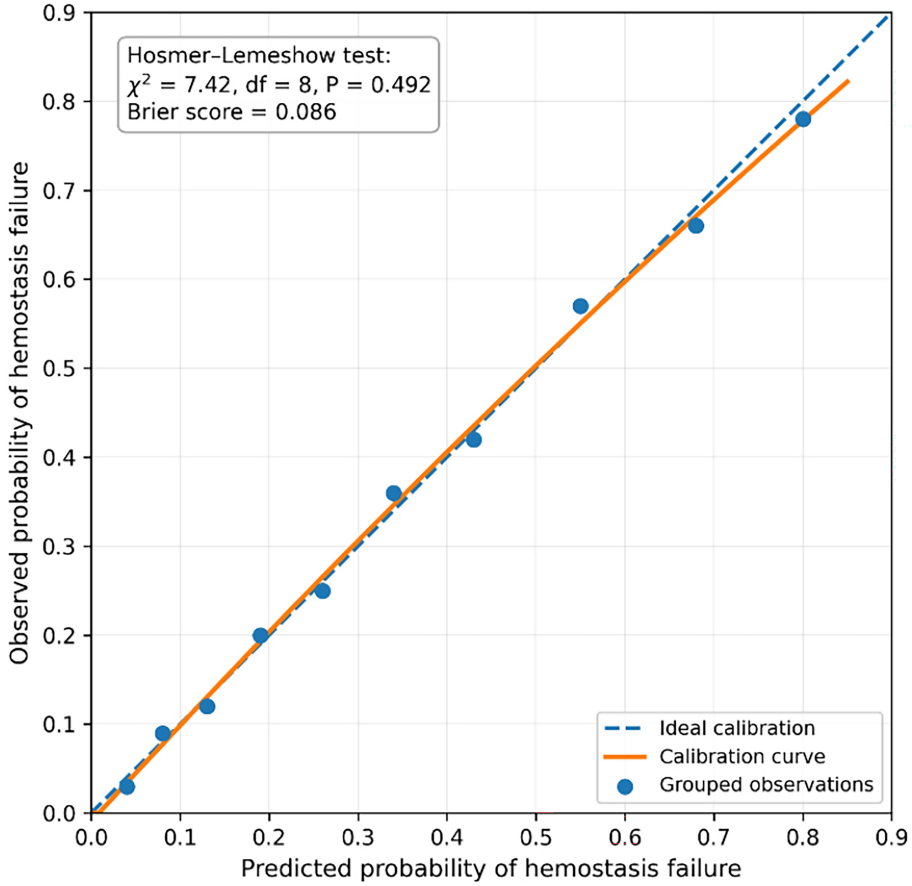

Fig. 3. Calibration plot of the predictive model for hemostasis failure.

curve closely approximating the ideal 45-degree reference line (Fig. 3). In addition, the Brier score was 0.086, suggesting acceptable apparent calibration in this cohort, while external validation remains necessary.

3.7 Results of Exploratory Subgroup Analysis

To further explore the potential heterogeneity of the association between dynamic precise decompression and hemostasis failure across different patient characteristics, exploratory subgroup analyses were performed (Fig. 4). The ACT cutoff of 275 s was derived from the exploratory ROC analysis and was therefore considered a post hoc, data-driven cutoff, whereas the BMI cutoff of 25 kg/m^2 was based on the commonly used clinical threshold for overweight/obesity. The results suggested that the association between dynamic precise decompression and lower odds of hemostasis failure appeared more pronounced in potentially high-risk subgroups. Specifically, in patients with ACT ≥275 s, dynamic precise decompression was associated with lower odds of hemostasis failure (OR = 0.45, 95% CI: 0.25–0.80). A similar finding was observed in overweight/obese patients with BMI ≥25 kg/m^2 (OR = 0.50, 95% CI: 0.28–0.88). In contrast, no statistically significant association was observed in the lower-risk subgroups, including patients with ACT <275 s or BMI <25 kg/m^2. Interaction testing suggested possible heterogeneity according to ACT level and BMI category; however, given the limited number of events, the observational design, and the post hoc nature of the ACT cutoff, these subgroup findings should be interpreted as exploratory and hypothesis-generating rather than confirmatory. The actual numbers of hemostasis failure events and total patients in each subgroup are shown in Fig. 4.

3.8 Dynamic Evolution of Multimodal Monitoring Indicators and Analysis Results of Decompression Characteristics

Based on the significant effect of ACT on the observed associations found in the above subgroup analysis, the hemodynamics and related clinical indicators were analyzed to further assess the potential guiding value of multimodal monitoring indicators during dynamic precise decompression. In terms of objective physical monitoring, continuous fingertip pulse and oxygen saturation monitoring showed that distal microcirculation perfusion tended to increase during stepwise balloon decompression. In the dynamic precise decompression group, the PI of the thumb on the puncture side decreased transiently after initial compression. At 5 min after the initial decompression, the PI increased significantly [(1.85 ± 0.42) *vs.* (1.21 ± 0.35), *p*

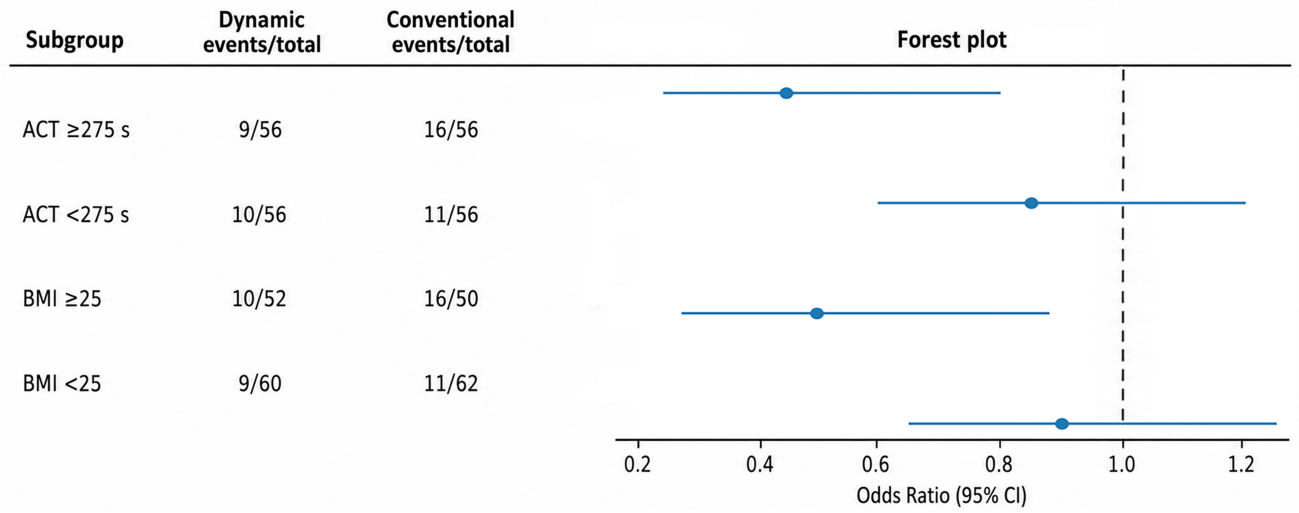

Fig. 4. Forest plot for exploratory subgroup analysis of the association between dynamic precise decompression and hemostasis failure across different subgroups. Event numbers are presented as events/total patients in the dynamic precise decompression and conventional compression groups for each subgroup. OR, odds ratio; CI, confidence interval.

< 0.001], and the volume amplitude recovered. In terms of biological parameters, ACT was moderately positively correlated with the time to first decompression using Spearman correlation analysis (r_s = 0.45, p < 0.001). Furthermore, the stratified analysis showed that the median time to first decompression was 60.0 min (IQR: 45.0–75.0) in patients with baseline ACT <275 s and 90.0 min (IQR: 75.0–105.0) in those with ACT ≥275 s, with statistically significant differences between the two groups (Z = 4.82, p < 0.001). These results demonstrate that multimodal monitoring parameters (including ACT and PI) reflected individual coagulation status and distal perfusion changes, which were correlated with the timing of the decompression strategy.

4. Discussion

In this study, an individualized dynamic precise decompression hemostasis strategy was developed and assessed based on multimodal monitoring indicators for hemostasis management after surgery *via* the distal radial artery approach. The results showed that in terms of safety, this strategy did not significantly differ from conventional compression in the rebleeding rate and hematoma incidence, suggesting no observed increase in bleeding-related complications in this cohort. On this basis, the dynamic precise decompression strategy was associated with shorter total compression time and a higher success rate of the first planned removal of hemostat. Meanwhile, with respect to patient experience, the dynamic precise decompression strategy was associated with lower pain scores, less local discomfort, and higher overall satisfaction scores. In terms of vascular outcomes, the 30 days distal radial artery occlusion rate was numerically lower in the dynamic precise decompression group, but the difference was not statistically significant.

The dynamic precise decompression strategy was associated with shorter overall compression time, a higher success rate of the first planned removal of hemostat, lower pain scores, and a lower incidence of local discomfort, without an observed increase in rebleeding or hematoma. These findings suggest that this strategy may be associated with more favorable hemostasis efficiency and patient experience, while its potential vascular signal requires further confirmation. As an important indicator for the coagulation status, ACT was positively correlated with the time to first decompression, and the time to decompression was significantly delayed in patients with higher ACT values, suggesting that the coagulation status directly influences the hemostasis stability. Therefore, stratification of decompression timing based on ACT may help avoid the risk of rebleeding due to premature deflation at an early stage [13]. PI and volume pulse wave may provide dynamic information on distal perfusion during decompression, offering a more objective physiological basis for pressure regulation. In this study, the PI after the first decompression was significantly higher than before decompression, suggesting that gradual relief of local compression was accompanied by higher distal microcirculation perfusion, which could serve as a safety signal for continuing decompression. When the PI decreased or blood oozing occurred, the decompression step was suspended or air was refilled according to the protocol [14]. This dynamic regulation process based on real-time feedback allowed decompression to be adjusted according to the real-time physiological status of each patient rather than relying solely on fixed time points. In addition, the dynamic precise decompression group showed higher peak blood flow velocity and larger vascular diameters at 24 h postoperatively, and a numerically lower, but statistically nonsignificant, incidence of distal RAO at 30 days follow-

up. Compared with previous studies mostly focusing on compression time setting or hemostatic device optimization, this study emphasized dynamic assessment and individualized adjustment during decompression, thereby providing preliminary evidence for a physiological feedback-oriented hemostasis strategy [15,16].

In this study, ACT, BMI and sheath catheter type were identified as factors associated with hemostasis failure. ACT increase, BMI increase and use of 6F sheath catheter were independently associated with elevated risk of hemostasis failure, while dynamic precise decompression was associated with lower odds. The predictive model established based on the above variables showed acceptable preliminary discriminatory performance, with an AUC of 0.82 and an optimism-corrected AUC of 0.79. However, given the limited number of outcome events, this model should be regarded as exploratory and should not be used as a definitive clinical prediction tool without external validation. From a perspective of mechanism, ACT reflects the anticoagulation and coagulation status, and its elevation indicates that the coagulation time is prolonged, and hemostasis stabilization is relatively delayed, so patients with high ACT values are more prone to rebleeding during decompression [17]. BMI increase may increase the thickness of local soft tissue and affect compression force transmission, making it more difficult to accurately control effective compression, thus increasing the difficulty of hemostasis [18]. The use of a larger sheath catheter means a larger diameter for vascular puncture and higher requirements for hemostasis strength and duration [19]. On this basis, dynamic precise decompression was individually adjusted by integrating coagulation status and perfusion feedback, which may partly explain its association with lower odds of hemostasis failure in the multiple logistic regression analysis. Furthermore, the subgroup analysis suggested a possible signal that the association between dynamic precise decompression and hemostasis failure may differ according to ACT and BMI. However, given the limited number of events, the post hoc derivation of the ACT cutoff, and the observational study design, these subgroup findings should be interpreted as exploratory and hypothesis-generating rather than evidence of differential treatment effects. From a clinical perspective, early assessment with ACT and BMI may help identify patients who require closer observation during compression and decompression, but whether these factors truly modify the association between decompression strategy and hemostasis outcomes requires confirmation in adequately powered studies. Meanwhile, the shorter compression time and lower patient discomfort observed in this cohort may be relevant to perioperative experience and workflow efficiency, while the nonsignificant numerical trend toward a lower 30-day RAO rate suggested a potential vascular patency advantage that should be interpreted cautiously [20]. In summary, this study provides preliminary evidence supporting individualized and stratified hemostasis management, but the observed associations require confirmation in larger randomized or externally validated studies.

From a clinical perspective, the dynamic precise decompression strategy may be relatively easy to incorporate into routine postprocedural care. It does not require complex additional procedures, and the main extra requirement is a pulse oximeter that can display PI and pulse waveform signals, together with the balloon hemostat already used in daily practice. In actual workflow, PI monitoring can be performed during the usual compression observation period, and the results can be reviewed together with local puncture-site findings before each decompression step. Therefore, this strategy may be more practical as a standardized nursing and operator-guided protocol rather than as an additional intervention. Staff training would mainly involve understanding the ACT based timing of first decompression, recognizing stable or declining PI and pulse waveform changes, and knowing when to pause decompression or refill air. In particular, patients with higher ACT values or higher BMI may require closer observation. However, before this approach can be widely adopted, its feasibility in centers with different staffing patterns, monitoring equipment, and postprocedural workflows should be further evaluated.

5. Limitation

Some limitations are worth noting in this study. First, this was a single-center prospective observational study with a relatively small sample size, so the extrapolation of the study results remains to be further verified in a multicenter population. Second, no randomized design was adopted, so potential selection bias and treatment-confounding may be present despite generally balanced baseline characteristics between the two groups. Treatment allocation was based on interventionalist judgment and patient condition, and no propensity-score matching, inverse probability weighting, or other advanced confounding-adjustment methods were performed. Therefore, residual confounding and confounding by indication cannot be excluded, and the observed differences between groups may partly reflect unmeasured baseline or procedural differences rather than the decompression strategy itself. Third, complete blinding was not feasible because of the visible differences between the two compression strategies. Therefore, subjective outcomes such as pain, local discomfort, and satisfaction, as well as decompression-related clinical decisions, may have been affected by observer or performance bias. In addition, no fixed numerical PI cutoff, predefined percentage decline, or automated alarm threshold was used in this protocol. The interpretation of “stable PI”, clinically relevant PI decline, and pulse waveform attenuation or flattening was mainly based on changes compared with the previous assessment and integrated with local puncture-site findings. Therefore, PI-guided decision-making remained partly operator-

dependent, which may limit reproducibility across centers. Future studies should further standardize quantitative PI thresholds and pulse waveform criteria to improve external applicability. Fourth, although the predictive model underwent calibration assessment and bootstrap internal validation, it was developed from only 31 outcome events with four predictors, resulting in an events-per-variable value of 7.75. Thus, model instability and optimistic performance estimates may still exist, and external validation is required before clinical application. Finally, the 30-d follow-up was insufficient to fully assess long-term vascular outcomes. In the future, large-sample, multicenter randomized controlled studies with extended follow-up periods are still needed to further verify the stability and long-term clinical value of the dynamic precise decompression strategy.

6. Conclusions

In conclusion, individualized dynamic precise decompression based on multimodal monitoring was associated with shorter compression time, better comfort-related outcomes, and no observed increase in bleeding complications. The 30-day distal RAO rate showed only a nonsignificant numerical trend toward a lower rate in the dynamic group. These findings suggest that dynamic precise decompression may serve as a potential supplement to conventional empirical compression, but causal efficacy cannot be inferred from this non-randomized study. Further multicenter randomized studies and external validation are needed before broader clinical application.

Availability of Data and Materials

All data reported in this paper will also be shared by the lead contact upon request.

Author Contributions

NX: Conceptualization, study design, data analysis, and manuscript drafting. MT: Investigation, data collection, and data interpretation. JW: Methodology, statistical analysis, and validation. YW: Data curation, visualization, and manuscript editing. YX: Supervision, project administration, conceptualization, and critical revision of the manuscript. All authors contributed to editorial changes in the manuscript. 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 was carried out in accordance with the guidelines of the Declaration of Helsinki and approved by the Medical Ethics Committee of our Nanjing Tongren Hospital (approval no. 2024-03-067-K001). All enrolled patients were fully informed of the study and voluntarily signed written informed consent forms preoperatively.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Hamilton GW, Dinh DT, Yeoh J, Brennan AL, Yudi MB, Reid CM, et al. Radial Versus Femoral Access for Percutaneous Coronary Intervention in Patients With Chronic Coronary Disease. The American Journal of Cardiology. 2026; 258: 63–68. https://doi.org/10.1016/j.amjcard.2025.08.038

[2] Mori H, Sakurai K, Ikari Y, Fukui K, Maeda A, Akashi Y, et al. Radial versus femoral access in patients undergoing primary percutaneous coronary intervention for ST-elevation myocardial infarction: A propensity-matched analysis from real-world data of the K-ACTIVE registry. Journal of Cardiology. 2023; 81: 189–195. https://doi.org/10.1016/j.jjcc.2022.09.001

[3] Sattar Y, Talib U, Faisaluddin M, Song D, Lak HM, Laghari A, et al. Meta-Analysis Comparing Distal Radial Versus Traditional Radial Percutaneous Coronary Intervention or Angiography. The American Journal of Cardiology. 2022; 170: 31–39. https://doi.org/10.1016/j.amjcard.2022.01.019

[4] Babunashvili AM, Pancholy S, Zulkarnaev AB, Kaledin AL, Kochanov IN, Korotkih AV, et al. Traditional Versus Distal Radial Access for Coronary Diagnostic and Revascularization Procedures: Final Results of the TENDERA Multicenter, Randomized Controlled Study. Catheterization and Cardiovascular Interventions. 2024; 104: 1396–1405. https://doi.org/10.1002/ccd.31271

[5] Achim A, Péter OÁ, Kákonyi K, Sasi V, Nemes A, Homorodean C, et al. The Role of Ultrasound in Accessing the Distal Radial Artery at the Anatomical Snuffbox for Cardiovascular Interventions. Life. 2023; 13: 25. https://doi.org/10.3390/life13010025

[6] Roy S, Kabach M, Patel DB, Guzman LA, Jovin IS. Radial Artery Access Complications: Prevention, Diagnosis and Management. Cardiovascular Revascularization Medicine. 2022; 40: 163–171. https://doi.org/10.1016/j.carrev.2021.12.007

[7] Maqsood MH, Pancholy S, Tuozzo KA, Moskowitz N, Rao SV, Bangalore S. Optimal Hemostatic Band Duration After Transradial Angiography or Intervention: Insights From a Mixed Treatment Comparison Meta-Analysis of Randomized Trials. Circulation. Cardiovascular Interventions. 2023; 16: e012781. https://doi.org/10.1161/CIRCINTERVENTIONS.122.012781

[8] Kheirabad MK, Mohebbi Z, Kalyani MN, Kojuri J. Vascular outcomes of early deflation of radial artery band following coronary angiography: A controlled clinical trial. Journal of Vascular Nursing. 2023; 41: 56–61. https://doi.org/10.1016/j.jvn.2023.04.001

[9] Lee JW, Kim Y, Lee BK, Yoo SY, Lee SY, Kim CJ, et al. Distal Radial Access for Coronary Procedures in a Large Prospective Multicenter Registry: The KODRA Trial. JACC. Cardiovascular Interventions. 2024; 17: 329–340. https://doi.org/10.1016/j.jcin.2023.11.021

[10] Jia D, Chen Y, Liu C, Ding S, Fang Y. Investigating optimal compression approach following radial artery puncture: a retrospective study. American Journal of Translational Research. 2024; 16: 2389–2397. https://doi.org/10.62347/BWUP6404

[11] Nemeth BT, Hizoh I, Nowotta F, Ruzsa Z, Szuk T, Kulyassa P, et al. Comparison of Safety of RADial comPRESSion De-

vices: A Multi-Center Trial of Patent Hemostasis following Percutaneous Coronary Intervention from Conventional Radial Access (RAD-PRESS Trial). Diagnostics. 2023; 13: 143. https://doi.org/10.3390/diagnostics13010143

[12] Yang S, Feng S, Wu H, Zhong C, Zhan S, Wang C, et al. Multimodal Brain Monitoring-Guided Anesthesia Management Improves Functional Connectivity, Enhances Recovery and Attenuates Postoperative Pain in Elderly Surgical Patients. Clinical Interventions in Aging. 2025; 20: 1757–1771. https://doi.org/10.2147/CIA.S551727

[13] Shin Y, Lee JM, Yu GI, Bae JS, Cho YH, Jang JY, et al. Predictors and clinical outcomes of incomplete hemostasis following transradial coronary intervention: the role of activated clotting time and procedural factors. Frontiers in Medicine. 2025; 12: 1661152. https://doi.org/10.3389/fmed.2025.1661152

[14] Aagren Nielsen CG, Rasmussen MB, Rhode PT, Bagner DV, Jensen RV, Jakobsen L, et al. Randomized comparison of rapid versus oximetry guided deflation of the transradial-band after coronary angiography or angioplasty. International Journal of Cardiology. 2025; 419: 132708. https://doi.org/10.1016/j.ijcard.2024.132708

[15] Didagelos M, Pagiantza A, Papazoglou AS, Moysidis DV, Petroglou D, Daios S, et al. Incidence and Prognostic Factors of Radial Artery Occlusion in Transradial Coronary Catheterization. Journal of Clinical Medicine. 2024; 13: 3276. https://doi.org/10.3390/jcm13113276

[16] Xu H, Cheng J, Zhang D, Shen L, Jiang Y, Zhai C. Effect of Radial Artery Compression with a Novel Automatic Pressure-Controlled Radial Compression Device: A Short-Term Prospective Interventional Pilot Study. Journal of Interventional Cardiology. 2023; 2023: 7533702. https://doi.org/10.1155/2023/7533702

[17] Didagelos M, Afendoulis D, Pagiantza A, Moysidis D, Papazoglou A, Kakderis C, et al. Treatment of radial artery occlusion after transradial coronary catheterization: a review of the literature and proposed treatment algorithm. Hellenic Journal of Cardiology. 2025; 84: 81–95. https://doi.org/10.1016/j.hjc.2025.01.008

[18] Sgueglia GA, Aminian A, Wiemer M, Kefer J, Gasparini GL, Ruzsa Z, et al. Impact of Anthropometric Measures on Distal vs Conventional Radial Access for Percutaneous Coronary Procedures. JACC. Advances. 2025; 4: 101565. https://doi.org/10.1016/j.jacadv.2024.101565

[19] Li Z, Wang Y, Song J, Wang S, Wang Y, Wu Y, et al. Distal radial access to prevent radial artery occlusion for STEMI patients (RAPID III): a randomized controlled trial. BMC Medicine. 2025; 23: 173. https://doi.org/10.1186/s12916-025-04005-1

[20] Yang Y, Zhu H, Zhai G. Enhancing heart and circulatory well-being through optimized radial artery techniques: a meta-analysis of hemostasis and patient comfort. Frontiers in Cardiovascular Medicine. 2025; 11: 1412479. https://doi.org/10.3389/fcvm.2024.1412479