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REVIEW ARTICLE

Early radial band deflation after transradial access coronary catheterization reduces complications: a systematic review

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ABSTRACT

BACKGROUND

Transradial access (TRA) coronary catheterization is widely used for coronary artery disease (CAD) management. However, complications such as pain, hematoma, and radial artery occlusion (RAO) often occur due to prolonged use of radial compression bands. Early deflation protocols have been proposed to minimize these complications while maintaining effective hemostasis. This systematic review evaluates the impact of early radial band deflation protocols on reducing TRA-related complications.

METHODS

A systematic literature search was conducted in ProQuest, PubMed, ScienceDirect, Sage Journal, and Scopus databases, including studies published between 2018 and March 2024. Inclusion criteria focused on randomized controlled trials (RCTs), cohort studies, and quasi-experimental studies evaluating radial band deflation protocols in TRA coronary catheterization patients. Outcomes included pain, hematoma, and RAO. Twelve studies were critically appraised using the Joanna Briggs Institute (JBI) tools and synthesized using narrative and quantitative approaches.

RESULTS

The review included eight RCTs, three cohort studies, and one quasi-experimental study involving a total of 4,477 patients. Findings revealed that early radial band deflation (1.5–2 hours) reduced pain and hematoma incidence compared to prolonged durations (>4 hours). RAO rates were significantly lower with gradual and early deflation protocols. However, shorter durations (<1.5 hours) slightly increased bleeding risk. Evidence supported the TR Band® Light Protocol as an effective and safe deflation strategy.

CONCLUSION

Early radial band deflation protocols effectively reduce TRA-related complications, enhancing patient comfort and safety. Standardized deflation protocols and further research, including innovative technologies, are recommended to optimize post-TRA care.

Keywords: Radial band deflation, transradial complication, arm pain, EASY hematoma, radial artery occlusion

INTRODUCTION

Cardiovascular diseases are the leading cause of death globally, claiming approximately 17.9 million lives annually. [1] More than half a billion people worldwide continue to be affected by cardiovascular diseases, resulting in 20.5 million deaths in 2021. [2] There has been an increase in the annual mortality rate from cardiovascular diseases by nearly 3 million since 2019.[1,2] Cardiovascular diseases encompass four entities: coronary artery disease (CAD), also known as coronary heart disease (CHD), cerebrovascular disease, peripheral artery disease (PAD), and aortic atherosclerosis.[3]

The incidence of coronary heart disease in Indonesia has been increasing year by year, with 1.5% (15 out of 1000) of the Indonesian population suffering from coronary heart disease.[4] Currently, the mortality rate due to CAD is 12.9%, meaning 13 out of every 100 deaths in Indonesia are caused by coronary heart disease.[5] Given the high mortality rate due to CAD, it consumes the largest healthcare budget. According to the Health Social Security Agency (BPJS-K) data in 2021, healthcare costs for CAD reached 7.7 trillion rupiahs.[6]

The management of coronary heart disease patients includes pharmacological therapy, percutaneous coronary intervention (PCI), and coronary artery bypass graft (CABG) surgery.[7] Annually, more than two million cases of CAD are treated with PCI and almost 400,000 with CABG.[8,9] However, CABG surgical trends have decreased as the use of PCI has increased. [9] Percutaneous coronary intervention is the most frequently performed procedure in the management of CAD, particularly for patients for whom open surgery is not feasible due to patient risk considerations and comorbid conditions.[10] Percutaneous coronary intervention is performed using two methods: transradial access (TRA) in 49.6% of patients and transfemoral access (TFA) in 50.4% of patients undergoing PCI.[11] The choice of access depends on patient characteristics and the expertise of the operating cardiologist.[12] Although transfemoral access is still more commonly chosen by operators due to ease of access and the femoral artery's larger size and anatomical strength,[13] the transradial approach for PCI is associated with fewer bleeding complications and access site complications.[14]

The PCI procedure uses a sheath introducer to maintain arterial access and control bleeding. Through the sheath, a guiding catheter is then inserted and directed toward the distal coronary artery until the condition and location of the blockage can be identified.[15] The removal of the sheath in PCI procedures with radial access is typically performed immediately after the PCI is completed.[16,17] Bleeding control during the radial sheath removal process is accomplished by applying mechanical pressure using a transradial band (TR Band®) directly at the transradial access site and maintaining it for several hours until hemostasis is achieved. [18,19] Numerous studies have demonstrated that the TR band offers clinical advantages, including ease of use, effective hemostasis, and a low rate of complications.[20–22] In the US, the TR band is the most commonly used compression device that is typically applied for 2–4 hours after transradial access (TRA). [23] China and Pakistan also widely use the TR Band [24,25], but standardized protocols for its safe removal and deflation are lacking. Likewise, in Indonesia the TR band is commonly used and included in the list of items issued by the Indonesian Government Goods and Services Procurement Policy Agency,[26] although there has been no research stating the prevalence of its use. On the other hand, the hemostasis process with mechanical pressure, such as using a transradial band, significantly causes pain and discomfort in patients compared to the use of vascular closure devices (VCDs).[27]

Pain associated with compression using a radial band after the removal of the transradial sheath is a common issue experienced by patients post-transradial PCI.[28] Approximately 1 in 20 patients undergoing transradial procedures experience arm pain post-procedure.[29] Another study found that 55% of transradial PCI patients experienced post-procedural pain, and 26% experienced prolonged pain.[30] If not properly managed this pain can cause patients to move excessively, thereby prolonging the hemostatic process and increasing the risk of bleeding at the vascular access site.[31]

In addition to pain, other complications that can occur with transradial access include hematoma and radial artery occlusion (RAO).[32] Hematoma occurs in 10% of patients undergoing transradial PCI and is most commonly located at the transradial puncture site.[33] Hematoma can result from the puncture procedure during the hemostasis process, which in transradial procedures is controlled using a radial band.

Furthermore, radial artery occlusion (RAO) is also a frequent complication in interventions using transradial access. The longer the duration of radial band application, the higher the risk of

RAO.[34] Radial artery occlusion can reduce the blood supply to the hand, leading to ischemic pain. RAO can be identified using Doppler ultrasonography or the modified Barbeau test with oximetry.[35] However, it is surprising that more than 50% of patients post-transradial PCI do not undergo reassessment for radial artery occlusion before discharge from the hospital.[36]

With the increasing number of cases of CAD and the use of TRA PCI, along with various complications arising from the procedure, including the use of radial compression bands, there is a need for a systematic review on the management of radial bands and their complications. Gradual deflation and shorter duration are believed to reduce the risks of pain, hematoma, and RAO.

The objective of the present systematic review is to evaluate the effectiveness of early deflation protocols for radial compression bands used after transradial access (TRA) coronary catheterization. This review focuses on assessing the impact of the protocols on reducing complications such as pain, hematoma, and radial artery occlusion (RAO). By synthesizing evidence from various studies, the review aims to identify optimal deflation practices and propose standardized post-procedural management strategies to enhance patient outcomes and minimize risks associated with TRA interventions.

METHODS

Protocol registration and reporting

This review employed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [37] guidelines, was registered in the PROSPERO database (ID: CRD42024589385), and is available from https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=589385.

Research question

The PICO framework (Population, Intervention, Comparison, Outcome) is a standardized approach used in this systematic review to precisely define the research question and guide the development of search strategies. Applying the PICO framework in this article provides several key benefits and serves specific purposes, as outlined in Table 1.

Inclusion and exclusion criteria

The authors applied the inclusion and exclusion criteria, such that studies were eligible for inclusion if they met the following criteria: (1) retrospective or prospective comparative studies; (2) patients who received TRA coronary catheterization, (3) studies comparing different radial band deflation times, and (4) studies reporting outcomes such as pain, hematoma, and radial artery occlusion. The authors also used these exclusion criteria: (1) systematic review, meta-analysis, conference report, expert comment, theoretical research, case report; (2) non-clinical studies, (3) studies without comparative outcomes, and (4) studies with poor quality or high bias levels. Critical appraisal was conducted on 12 articles regarding the selection, management, and handling of transradial access, consisting of 8 randomized controlled trials, 3 cohort studies, and 1 quasi-experimental study.

Search strategy

The authors conducted several search processes to obtain relevant articles on radial band use and TRA PCI complications. During the search process, the authors used several keywords with Boolean operators, such as “Transradial band”, “Transradial band AND pain”, and "deflate AND transradial AND band AND/OR pain” in five databases, namely ProQuest, PubMed, ScienceDirect, Sage Journal, and Scopus.

The authors investigated several relevant published articles in the International English version. After selecting several similar studies, the authors collected the relevant articles by limiting them to publications from the last five years, covering the period from 2018 up to 12 March 2024.

Table 1. PICO and research question

Population	Patients undergoing transradial access coronary catheterization
Interventions	Radial band early deflation protocols
Comparison	Longer deflation duration
Outcomes	Complication reduction (pain, hematoma, and radial artery occlusion)
Research Question:	In patients undergoing transradial access coronary catheterization, is radial band early deflation more effective than longer deflation duration for complication reduction?

Study selection

After removal of duplicates, 2 authors (RMN and AW) independently screened titles and abstracts for potential eligible studies. Subsequently, both authors independently appraised full-text content and applied our inclusion and exclusion criteria. Discrepancies in inclusion of articles were resolved by a third reviewer (TH).

Data extraction

Data extraction was performed by 2 authors (RMN and AW) independently, including study design, year of publication, duration of follow-up, study population characteristics (e.g. mean age, sex, distribution), primary and secondary outcome measurements, and main results of the studies. Disagreements were resolved by a third reviewer (TH).

Risk of bias assessments

The results of risk of bias assessment are presented in Table 2.

Data synthesis

The data synthesis process for this systematic review was performed to systematically integrate and interpret findings from the included studies. Both qualitative and quantitative data were synthesized to address the research question. A narrative approach was used to describe the key characteristics, methodologies, and results of the included studies. However, due to variability in deflation protocols, study populations, and outcome assessment methods, direct meta-analytic pooling was limited.

Levels of evidence

The level of evidence for this systematic review was evaluated to determine the quality and reliability of the findings from the included studies. The levels of evidence were classified based on widely accepted hierarchies, such as those proposed by the Oxford Centre for Evidence-Based Medicine (OCEBM). Each included study was assessed for its position on the evidence hierarchy and its contribution to the overall conclusions.

Level 1: RCTs, eight of the included studies were RCTs, examining various deflation protocols and their impact on outcomes such as pain, hematoma, and radial artery occlusion (RAO). These studies provided strong evidence supporting the efficacy of early radial band deflation (1.5–2 hours) in reducing complications while maintaining effective hemostasis.

Level 2: Cohort studies, three cohort studies were included, offering observational data on the association between deflation protocols and outcomes. Although these studies lacked randomization, they provided valuable insights into real-world applications, identifying predictors of complications such as RAO and post-procedural pain. For example, studies highlighted that prolonged compression (>4 hours) increases the risk of RAO and patient discomfort.

Table 2. Joanna Briggs institute (JBI) risk of bias assessment

Authors	Question												%Yes	Risk
	1	2	3	4	5	6	7	8	9	10	11	12		
Randomized Controlled Trial (38)														
Kheirabad et al.[39]	✓	✓	✓	✓	--	✓	✓	✓	✓	✓	✓	✓	91.6	Low
Wu et al.[40]	✓	✓	✓	✓	✓	--	✓	✓	✓	✓	✓	✓	91.6	Low
Kılıç et al.[41]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	100	Low
Santos et al.[22]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	100	Low
Ahmed et al.[42]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	100	Low
Gupta et al.[43]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	100	Low
Chen et al.[44]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	100	Low
Dharma et al.[29]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	V	100	Low
Quasi-Experimental Study														
Roberts et al.[46]	✓	--	✓	✓	✓	✓	✓	✓	✓				88.8	Low
Cohort Study														
Bardooli et al.[25]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		100	Low
Cheung et al.[48]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		100	Low
Hashmi et al.[49]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		100	Low

Level 3: Quasi-experimental study, one study was included, which applied an intervention protocol without randomization. While this study provided important data on the feasibility and safety of gradual deflation, its methodological limitations (e.g., selection bias and lack of blinding) reduced its evidence strength compared to RCTs.

RESULTS

Study selection

The results of this literature review are explained as follows: Figure 1 illustrates the study selection procedure. A total of 1076 references pertaining to the subject were retrieved from five electronic databases. Conversely, certain articles were excluded due to insufficiently comprehensive titles and abstracts, topics unrelated to the study, those published as letters to the editor or short communications, and those lacking full-text availability. Ultimately, 12 studies were thoroughly examined.

Study characteristics

This study reviews 12 articles related to radial band deflation and complications of TRA PCI after several articles were selected and it was decided not to use them because they did not have a significant enough relationship to the review. The reviewed articles are presented in Table 3.

These 12 articles collectively support the implementation of Evidence-Based Practice Nursing (EBPN) in hemostasis management by early radial band deflation in transradial access following coronary catheterization to reduce complications such as pain, hematoma, and radial artery occlusion (RAO).

Two studies specifically discussed the gradual deflation of the transradial compression band with different protocols.[39,46] Kheirabad et al.[39] implemented deflation of 5 mL of air every 15 minutes until the band was removed. Roberts and Niu [46] described a protocol called the TR Band® "Light" Protocol where deflation occurred 60 minutes after band application with a reduction of 2 mL of air, followed by deflation of 2 mL at 80 minutes, 3 mL at 100 minutes, and complete air removal at 120 minutes, achieving an 89% success rate with an average removal time of 126±20 minutes. Both studies indicated that earlier deflation and faster removal duration can reduce pain, hematoma, and RAO in transradial access following coronary catheterization.

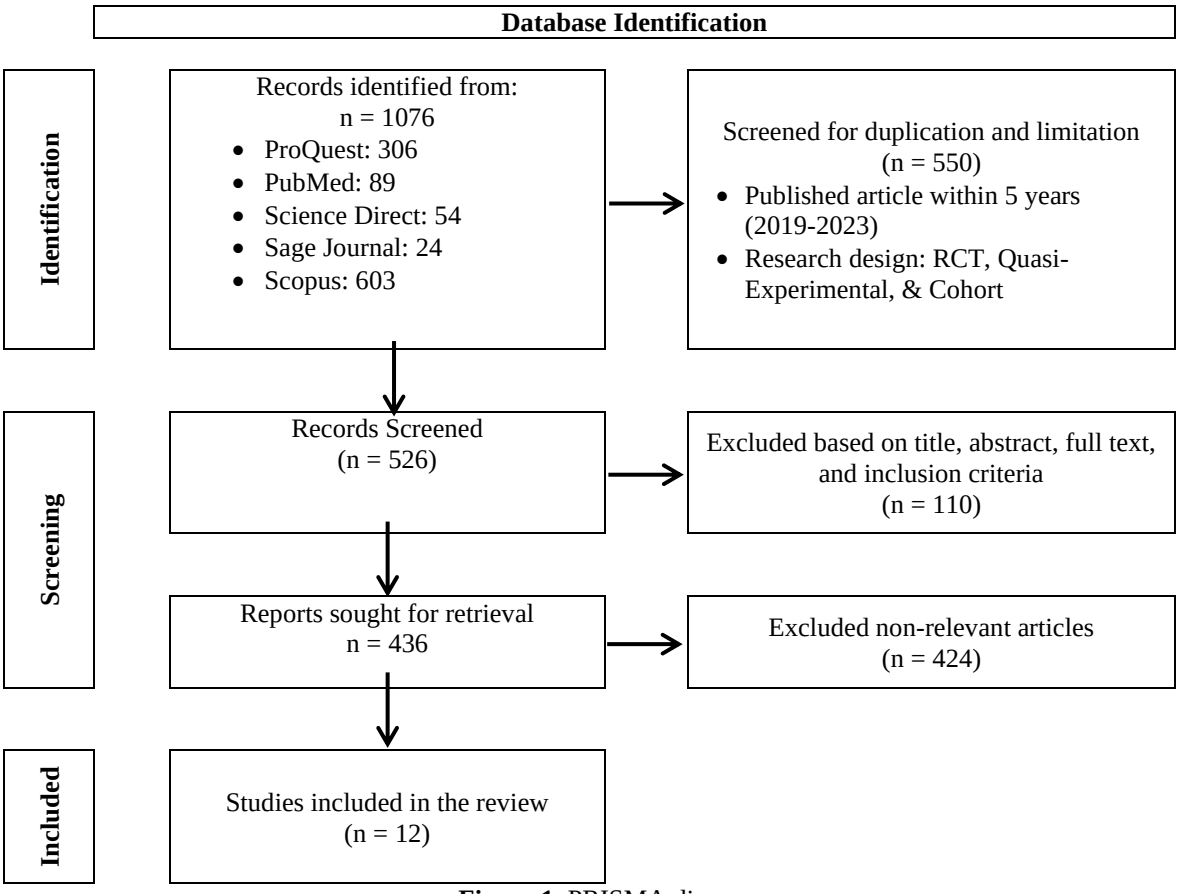

Figure 1. PRISMA diagram

Table 3. Study design and outcomes of the included studies

Authors	Country	Objective	Design	No. of participants	Intervention	Outcomes
Kheirabad et al.[39]	Iran	Comparing the deflation time of the radial band to assess pain complaints, incidence of hematoma, radial artery occlusion, as well as efficacy and safety between the control and intervention groups	Randomized controlled trial	70	Applying gradual radial band deflation of 5 mL of air every 15 minutes. Interventional Group (n = 35), radial band was removed in 1.5 hours. Control Group (n = 35), the radial band was removed in 2 hours.	The intervention group experienced a notable decrease in pain severity over time, both groups demonstrated similar demographics and outcomes regarding hematoma development and RAO.
Wu et al.[40]	China	Comparing the impact of two types of radial bands on pain levels, bleeding, hematoma, ecchymosis, skin lesions, and local infection after procedures using transradial access	Randomized controlled trial	60	Evaluating discomfort including pain using Visual Analog Scale (VAS) and local complication at the puncture site (bleeding, hematoma, ecchymosis, skin lesions, local infection) at 1, 6, and 24 hours after the procedure, between TR Band and new radial artery hemostatic device.	Both groups utilizing hemostatic devices achieved sufficient hemostasis without any instances of bleeding failure. The novel radial artery hemostasis device demonstrated superiority over the TR band in alleviating pain and reducing swelling. No notable distinctions were observed in terms of bleeding, hematoma, ecchymosis, skin impairment, or local infection between the two groups.
Kılıç et al.[41]	Brazil	Identifying access site pain level differences among traditional radial artery (TRA), distal radial artery (DRA), and transfemoral artery (TFA)	Randomized controlled trial	540	Assessing post-procedure pain immediately using the Visual Analog Scale (VAS) from 0 to 10 and categorized into three groups (mild, moderate, and severe) in three different puncture access sites (TRA, DRA, and TFA)	Significant differences in pain ($p<0.001$) for each access site were observed, lowest in TFA (2.7±1.6), then TRA (3.9±1.9) and DRA (4.9±2.1). It showed that pain commonly occurred in cardiac catheterization access site.
Santos et al.[22]	Brazil	Comparing the use of the TR Band® hemostasis method and conventional dressings with gauze and adhesive bandages in terms of the incidence of Radial Artery Occlusion (RAO)	Randomized controlled trial	600	Assessing RAO immediately after the procedure and again 30 days later. Patients undergoing transradial catheterization were divided into an intervention group with 301 patients using the TR Band® and a control group with 299 patients using conventional dressings (adhesive dressings).	The incidence of RAO after TR Band® application was higher than after conventional adhesive dressings. The incidence of RAO post-procedure and at 30 days with both TR Band® and conventional adhesive dressings was similar, with the only predisposing factor being peripheral vascular disease.

Ahmed et al.[42]	Ireland	Comparing the use of conventional hemostasis, patented radial artery bands, and the simultaneous ulnar and radial compression (SURC) technique in relation to the incidence of Radial Artery Occlusion (RAO)	Randomized controlled trial	450	Assessing RAO using duplex ultrasound at 1-hour post-radial compression removal and reassessing after 1 month. Compression techniques applied were conventional hemostasis (Group A), patented TR Band® hemostasis (Group B), and the SURC (Group C), each group consisting of 150 patients.	One-hour post transradial band removal, the incidence of RAO was significantly lower in patients in SURC compared to TR Band and conventional dressing. This trend remained consistent in the subsequent one-month evaluation.
Gupta et al.[43]	China	Evaluating the feasibility of distal transradial access compared to conventional transradial access for coronary angiography.	Randomized controlled trial	420	Comparing various parameters (success rate, single-puncture, hemostasis time, operation time, fluoroscopy time, contrast volume) and procedure-related complications (pain, hand discomfort, hematoma, swelling) between distal transradial access (dTRA) and transradial access (TRA)	The success rate of distal radial access was comparable to that of transradial access (96% vs. 98%). Single-puncture success was higher with transradial access than with distal radial access. RAO was more frequent in TRA than in dTRA. Post-procedural pain persistence and hand discomfort were significantly more common in TRA than in dTRA. Hemostasis time after the procedure was shorter in dTRA than TRA. There were no significant differences between dTRA and TRA in terms of operation time, fluoroscopy time, and contrast volume, hematoma or swelling.
Chen et al.[44]	China	Comparing the effects of distal transradial access (dTRA) and transradial access (TRA) on long-term radial artery occlusion (RAO).	Randomized controlled trial	701	Evaluating the incidence of long-term radial artery occlusion (RAO) using ultrasound examination at 3 months post-discharge from the hospital. Besides long term RAO, RAO within 24 hours, success rate of puncture, puncture attempts, fluoroscopy time, and other complications were also evaluated.	The incidences of RAO either long-term (3 months) or within 24 hours, bleeding, or hematoma were lower in dTRA than TRA. The puncture success rate and single-puncture success rate were significantly higher in TRA compared to dTRA. There were no significant differences in procedural success rate, total fluoroscopy time, or the incidence of other access-related complications.

Roberts et al. [46]	United States	Identifying the success rate of the protocol and the impact of gradual air pressure reduction on the removal of the radial band after transradial percutaneous coronary intervention	Quasi-experimental study	67	Application of gradual radial band deflation protocol started at minute 60th as: - 60th deflating 2 mL - 80th deflating 2 mL - 100th deflating 3 mL - 120th deflating all remains and removing the radial band If oozing occurred, the deflated amount of air was re-inserted, and the weaning was resumed after 20 minutes.	Hemostasis was achieved in 59 (89%) patients, with 7 (11%) patients requiring air refilling during weaning. The average duration achieved was 126 ± 20 minutes. The most common complication was pain, followed by hematoma (5%) and RAO (3%).
Dharma et al. [29]	Indonesia	Identifying predisposing factors for post-procedural arm pain following transradial catheterization	Retrospective randomized control trial	1706	Arm pain was assessed using the Visual Analog Scale (VAS), where a pain score > 4 was defined as moderate to severe pain in the forearm access site, unrelated to hand ischemia, and evaluated one day after the procedure. Logistic regression was used to identify predictors of post-procedural arm pain.	The overall incidence of post-procedural arm pain one day following transradial coronary catheterization was 4.5%, with associated covariates including hemostasis compression > 4 hours, radial artery occlusion, radial artery diameter, and multiple puncture attempts.
Bardooli et al. [25]	Bahrain	Evaluating the success of radial band removal in less than 4 hours, incidence of bleeding, radial artery occlusion (RAO), and hematoma following the use of a radial artery compression band	Cohort study	100	Comparing the success of two pneumatic compression devices (TR Band vs. AIR Band) post transradial access coronary catheterization. TR Band inflated 13-15 mL and AIR Band inflated 7 mL.	Successful removal within 4 hours was achieved in AIR band (64%) and TR Band (4%). The incidence of bleeding and RAO were similar between the two bands. No hematoma occurred in any patients with both types of band.
Cheung et al. [48]	Netherlands	Identifying symptoms of upper limb dysfunction following TRA PCI procedures and administering the corresponding therapy.	Cohort study	433	Following up TRA PCI complications until their last follow-up at the hand center 5-7 months after the procedure. Patients undergoing TRA PCI were referred to a hand center due to new or worsening upper limb symptoms.	Most of the patients experienced pain (9%). Carpal tunnel syndrome (n = 18) and osteoarthritis (n = 15) were the most common complications. In patients requiring further treatment to alleviate hand complaints, immobilization was frequently administered. Persistent symptoms continued in 17 patients despite receiving treatment.

Hashmi et al. [49]	Pakistan	Assessing the frequency of radial artery occlusion following the use of radial artery bands post-transradial coronary catheterization	Cohort study	180	Evaluating the occurrence of radial artery occlusion (RAO) using the Barbeau test at 24 hours post-transradial coronary catheterization.	Radial artery occlusion was found in 14 (7.8%) patients. There were no significant differences in RAO between age and gender groups. Additionally, comorbidities such as diabetes mellitus, hypertension, and smoking were observed to increase the risk of radial artery occlusion, although this was only significant in diabetes mellitus (p=0.048).

A randomized controlled trial (RCT) comparing the safety of a new radial artery hemostasis device with the TR Band® showed that the new device significantly reduced pain and swelling, but not numbness at the distal access site.[40] Arm pain was also identified in a retrospective study involving 1706 patients undergoing coronary catheterization through transradial access, with an incidence of 4.5% patients, associated with hemostasis compression of more than 4 hours, RAO, radial artery diameter <2.8 mm, and repeated puncture attempts.[29] A prospective cohort study of 433 patients undergoing transradial PCI also reported post-procedural pain as the most common complication in 39 (9%) patients.[48] Pain scores assessed with VAS varied by access type; lowest pain score (VAS 2.7±1.6) experienced in transfemoral access, followed by transradial access (VAS 3.9±1.9) and distal radial access (VAS 4.9±2.1).[41]

A cohort study compared two radial compression bands (AIR Band® and TR Band®) regarding the success of removal in less than 4 hours, bleeding, RAO, and hematoma. Among 50 patients in each group, the success rate for removal < 4 hours was higher with the AIR Band® (64%) than the TR Band® (4%), with similar bleeding and RAO rates between both bands, and no hematoma observed.[25] RAO incidence was also studied in an RCT (n=600) comparing the TR Band® and conventional dressings (gauze and adhesive bandage). RAO incidence was higher with the TR Band® than with conventional dressings, but at 30-day follow-up, RAO was observed in 5 TR Band® patients and 7 conventional dressing patients. Another RCT (n=450) compared three hemostasis methods:[42] conventional dressings, TR Band®, and SURC. RAO 1-hour post TR band removal was significantly lower with SURC compared to conventional dressings and TR Band®. This trend remained consistent at 1 month. A cohort study of 180 patients undergoing transradial coronary catheterization indicated that the transradial pneumatic band is effective and safe for preventing RAO, with diabetes mellitus, hypertension, and smoking increasing RAO risk, but only the increased RAO risk in diabetes mellitus being statistically significant.[49]

Beyond hemostasis methods, the type of access also affects RAO incidence. The transradial access (13%) carried a higher RAO risk compared to distal radial access (2%), although the success rate of obtaining access in a single puncture is higher with transradial than with distal radial access. Persistent pain is more frequent with transradial than with distal radial access, but hemostasis time is shorter with transradial (24 ± 6.23 minutes) compared to distal radial access (28 ± 7.86 minutes).[43] Clinically, the RAO risk increases when the accessed vessel is closer to the radial artery, such as in transulnar, transbrachial, or transfemoral access, which may lead to other vascular complications at different rates. One RCT also compared long-term (3 months post-hospital discharge) RAO incidence in 701 patients using distal radial access versus transradial access, showing lower long-term RAO with distal radial access compared to transradial access. Bleeding and hematoma incidences were also lower with distal radial access.[44]

Complications commonly associated with transradial access are related to the duration of radial compression device deflation, as summarized in Table 4. Additionally, other complications such as arm discomfort, carpal tunnel syndrome, and osteoarthritis may also arise with the use of transradial access.[43,48]

Table 4. Common TRA complications related to deflation duration [25,39,40,42,46]

Deflations	Complications
< 90 minutes (1.5-hours)	Pain, Bleeding, Swelling
1.5 hours	Pain, Bleeding
2 hours	Pain
2-4 hours	Pain, Hematoma
> 4 hours	Pain, Hematoma, RAO

Risk of bias in individual trial outcomes

Across all study designs, the primary outcomes—pain, hematoma, and radial artery occlusion (RAO)—were consistently measured using validated tools such as the visual analog scale (VAS) for pain and ultrasound or the Barbeau test for RAO. However, the lack of standardized timing for outcome assessment across studies introduced heterogeneity, which could impact the comparability of results.

DISCUSSION

This study provides a systematic review of the optimal management of radial band deflation and its associated complications in patients undergoing transradial access (TRA) for coronary catheterization, either coronary angiography (CAG) or percutaneous coronary intervention (PCI). The findings highlight the importance of early radial band deflation protocols in reducing

complications such as pain, hematoma, and radial artery occlusion (RAO).

The results from the studies confirmed that both 1.5- and 2-hour deflation times result in similar efficacy and safety, with less pain reported in the shorter-duration.[49] Another study also demonstrates that a 2-hour duration for radial band deflation is both effective and safe, but a 90-minute (1.5-hour) duration has higher risk for bleeding.[34] In addition, a duration exceeding 2 hours increases the risk of hematoma formation. This finding confirms that longer durations increase the risk of hematoma, while shorter durations may prevent bleeding without significantly affecting the incidence of RAO. The puncture site also affects hemostasis; for example, distal transradial access (dTRA) generally achieves hemostasis more rapidly than conventional transradial access (TRA).[43]

The choice of coronary catheterization access depends on the operating cardiologist.[12] Currently, transradial access (TRA) is the preferred option in the field due to its ease of access and minimal risk profile.[50,51] Post-procedural hemostasis management for transradial procedures most commonly employs a radial compression device (TR Band). Although the TR Band is widely used, the deflation protocol and removal duration vary significantly in clinical practice, as no standard has been established.

A variety of deflation protocols and durations are implemented, ranging from rapid radial band removal within 90 minutes to over 4 hours.[25,29,34,39,46] These differences in compression device management can lead to varying complications. Complications arising from transradial access may include hand discomfort, pain, hematoma, swelling, and radial artery occlusion.[29-34] Although complications are numerous, clinical practice rarely considers the underlying factors contributing to them. For example, RAO is seldom assessed after the TRA procedure or before the patient is discharged from the hospital.

Although a 2-hour deflation duration is considered the safest and most efficacious, bleeding complications still frequently occur at this duration in clinical practice. This may be influenced by factors such as high doses of heparin,[52] multiple puncture attempts, and abnormal coagulation parameters such as activated clotting time (ACT) or activated partial thromboplastin time (aPTT). Similarly, RAO complications are not only related to deflation durations of over 4 hours but are also affected by the accessed artery's diameter and repeated puncture attempts.[29] Additionally, the selection of deflation duration can vary among clinicians in practice. Therefore, it is essential for healthcare institutions to establish standardized protocols for consistent care.

The authors' intellectual reflection is evident in the critical analysis of various deflation protocols and their impacts on patient outcomes. The logical argumentation is supported by comparative studies, such as the study of Roberts and Niu,[23] who applied an early and gradual air pressure deflation protocol within 2 hours, resulting in an 89% success rate in achieving hemostasis with minimal complications. This supports the finding that early radial band deflation can reduce complications in TRA coronary catheterization, corroborating basic hemostasis concepts.

The discussion further relates to other research findings by comparing different hemostatic devices and their effectiveness. For example, Wu et al.[40] compared a novel compression device with the TR Band®, finding the former to be superior in reducing pain and swelling, although both devices were equally effective in preventing major complications. This comparative approach strengthens the discussion by aligning it with existing literature and providing a comprehensive overview of current practices and their outcomes.

The implications of these findings are significant for both theoretical and practical applications. Theoretically, the study supports the concept that optimal deflation protocols can minimize complications, thus enhancing patient comfort and safety. Practically, it suggests that implementing a standardized 2-hour deflation protocol, as exemplified by the TR Band "Light" Protocol, could improve clinical outcomes. Moreover, the potential development of automated AI-based deflation devices represents an innovative direction for future research and clinical practice, potentially further reducing complications and standardizing care.

For practical implications, a 2-hour deflation duration is optimal for reducing complications in TRA PCI that is well-supported by the results. Future research should focus on refining deflation protocols and exploring automated solutions to enhance patient care. The practical applications of these findings are clear, suggesting immediate implementation in clinical settings to improve patient outcomes and reduce healthcare costs associated with complications. This study

provides a comprehensive and insightful discussion, contributing valuable knowledge to the field of interventional cardiology.

However, the study also acknowledges limitations, including the variability in study designs and patient populations among the reviewed articles, which may affect the generalizability of the findings. Additionally, while the discussion is grounded in robust evidence, there is a need for caution against excessive speculation regarding the superiority of one deflation protocol over another without further large-scale randomized trials.

This systematic review highlights significant advancements in managing radial band deflation following transradial access coronary catheterization, but several areas require further exploration and improvement. One critical direction is the refinement of deflation protocols tailored to diverse patient populations. Variables such as radial artery size, comorbid conditions, and procedural factors (e.g., anticoagulant levels or hemostatic device types) should guide protocol optimization. Randomized controlled trials with larger sample sizes are necessary to validate the safety and efficacy of shorter deflation durations.

Innovative technologies, such as AI-based automated deflation devices, present a promising area of research. These devices could provide precise control over deflation timing and pressure adjustments while integrating real-time monitoring of hemostasis to further minimize complications. Additionally, there is a pressing need for standardization of radial band deflation practices. Collaborative efforts among professional societies and healthcare institutions are essential to establish evidence-based guidelines for consistent and safe clinical practices.

Long-term outcome assessments are also crucial. Studies evaluating the impact of radial band deflation protocols on chronic complications, such as persistent pain, radial artery occlusion, or functional impairments, will offer valuable insights into the broader implications of procedural choices on patient recovery and quality of life. Simultaneously, research focusing on patient-reported outcomes, including comfort, pain levels, and satisfaction, can help refine protocols to prioritize patient experience alongside clinical safety.

Another important avenue is the economic evaluation of different deflation protocols. Assessing the cost-effectiveness of manual versus automated systems can help determine their feasibility and accessibility, especially in resource-limited settings. Furthermore, the findings from this review could be extended to other procedures using transradial access, such as peripheral angiography or electrophysiological studies, by exploring the adaptability of the protocols to these contexts.

By addressing these areas, future research can enhance the precision, safety, and patient-centeredness of radial compression band management, ensuring better clinical outcomes and patient satisfaction in transradial procedures.

CONCLUSION

Complications of TRA PCI and radial compression band use include pain, hematoma, and RAO. Proper management of radial compression band use after coronary catheterization is essential to reduce the risk of these complications. The appropriate duration and method of radial band removal can potentially reduce this risk. Currently, the TR Band® Light Protocol is the preferred protocol for radial compression band removal according to the most effective and safest duration, which is 2 hours (120 minutes). Research on effective and efficient methods of radial compression device removal should continue to be developed and improved. It is possible to create an automated deflation device with AI-based technology that can detect oozing at TRA puncture sites and achieve the optimal duration of radial compression band removal.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this research.

Author Contributions

RMN: conception and design, data acquisition, analysis and interpretation, drafting the article, final approval of the version to be published. AW: data acquisition, analysis and interpretation, critical revision of the article, final approval of the version to be published. TH**:** data acquisition, analysis and interpretation, critical revision of the article, final approval of the version to be published. All authors have read and approved the final manuscript.

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Data Availability Statement

The data supporting the findings of this study are available upon reasonable request from the corresponding author. The data includes the extracted results and critical appraisals of the studies reviewed and are stored in compliance with institutional and ethical guidelines. Due to privacy and ethical considerations, access to raw data may be restricted to authorized requests only.

Declaration of use of AI in Scientific Writing

Artificial Intelligence tools, including language models and grammar-checking software, were used to enhance the clarity, grammar, and structure of this manuscript. The AI was not involved in generating novel content or conducting the data analysis but was employed for editing and formatting purposes. All intellectual content, critical interpretations, and conclusions are the result of the authors' efforts. The authors take full responsibility for the integrity and accuracy of this work.

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