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Summary of the best evidence for the safe use of pneumatic tourniquet in limb surgery

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Abstract

Purpose To retrieve, evaluate, and summarize the best available evidence regarding the safe use of pneumatic tourniquet in patients undergoing Limb surgery, providing guidance for preoperative assessment, operation methods and precautions, complication prevention and treatment in clinical practice.

Methods Using the PIPOST tool, we formulated an evidence-based question, conducted searches in relevant Chinese and international databases and websites for clinical decisions, guidelines, evidence summaries, systematic reviews, and expert consensus on the use of limb surgical tourniquets. The search was limited to literature published until September 30, 2023. Quality assessment and evidence extraction were performed on eligible documents.

Results This study included a total of 13 articles, including 2 clinical decision-making articles, 3 guidelines, 5 expert consensus articles, 1 standard and 2 systematic reviews. A total of 34 best pieces of evidence recommendations were summarized across 10 aspects, including indications and contraindications for the use of pneumatic tourniquets, preoperative evaluation of operators, selection and placement of tourniquet cuffs, tourniquet inflation, monitoring during inflation, tourniquet deflation, common complications and prevention, equipment safety, documentation, and training and education.

Conclusion The best evidence summarized in this study can provide reference for clinical medical staff to safely use pneumatic tourniquets, but in clinical practice, targeted selection and application of evidence should be combined with specific situations to improve the safety and hemostatic effect of pneumatic tourniquet use.

Keywords Limb surgery, Pneumatic tourniquet, Safe usage, Evidence summary, Evidence-based nursing

Introduction

The pneumatic tourniquet (abbreviated as tourniquet) is a commonly used hemostatic device in clinical limb surgery. It blocks blood flow to the surgical site of the limb, reduces bleeding, creates a "bloodless" field of view, and improves surgical safety and efficiency. Although the handling of a tourniquet is relatively simple, there still exists a phenomenon of non-standard operation. Such as improper cuff selection, loosely applied cuff, high/low cuff pressure and prolonged inflation [1, 2], as well as solutions used for operative preparation underneath the tourniquet and remain there during tourniquet inflation [3], and improper cuff deflation [4] et al. This can lead to adverse outcomes for patients postoperatively, including Increased bleeding, nerve and soft tissue injuries, thromboembolism, increased pain, burn, extended recovery times, and decreased muscle strength [5–7]. The correct management of indications, contraindications, and potential risk factors associated with the use of limb

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surgical tourniquets, along with a focus on the details of tourniquet application, is paramount for ensuring the safe utilization of limb surgical tourniquets in limb surgery. At present, domestic and foreign research mostly focuses on the effectiveness of tourniquet use [8, 9], the impact of inflation pressure settings, and protective measures on complications [10, 11]. However, there remains controversy within relevant guidelines and expert consensus regarding tourniquet pressure settings, duration of inflation, and lack of systematic and scientific guidance for the entire process of intraoperative tourniquet application. Therefore, this study employs an evidence-based approach to systematically retrieve, summarize, and integrate the best available evidence from China and other countries worldwide concerning the safe use of tourniquets in limb surgery. Intended to establish clinical guidelines for the safe and effective use of pneumatic tourniquets. This includes defining clear indications and contraindications, optimizing preoperative assessments, ensuring the appropriate selection of cuffs, and setting accurate pressure and duration parameters. Additionally, the study aims to highlight the importance of monitoring during tourniquet use and document records, et al. to minimize intraoperative bleeding and reduce postoperative complications, thereby enhancing overall surgical safety.

Materials and methods

Problem formulation

Using the PIPOST tool developed by the Evidence-Based Nursing Center at Fudan University in China [12, 13], we formulated an evidence-based nursing question as follows: P (population): patients undergoing limb surgery who use pneumatic tourniquets during the procedure. I (intervention): the safe use of pneumatic tourniquets, including indications and contraindications, preoperative assessment, tourniquet and placement selection, exsanguination, pressure and time settings, inflation and deflation, inflation monitoring, complications prevention, instrument maintenance and upkeep. P (professional): surgeons, anesthesiologists, and circulating nurses. O (outcome): the effectiveness and complications associated with pneumatic tourniquet use, such as surgical duration, intraoperative bleeding volume, total blood loss, pain, thromboembolism, nerve injuries, and skin pressure injuries. S (setting): operating room. T (type of evidence): clinical decisions, evidence summaries, systematic reviews, guidelines, and expert consensus.

Search approach and strategy

Following the "6S" evidence model [14], searches were conducted as follows: (1) Clinical Decision Support Systems: BMJ Best Practice, UpToDate. (2) Guideline Websites and Professional Association Websites: National Guideline Clearinghouse (NGC), Registered Nurses Association of Ontario (RNAO), Scottish Intercollegiate Guidelines Network (SIGN), National Institute for Health and Care Excellence (NICE), New Zealand Guidelines Group, Canadian Medical Association Clinical Practice Guidelines Database, Association of perioperative Registered Nurses (AORN), Association of Surgical Technologists (AST), British Orthopaedic Association(BOA), Chinese Nursing Association Operating Room Professional Committee, MedSci China Guideline Network, China Clinical Guidelines Library (CGC). (3) Databases: Nursing Consult, Joanna Briggs Institute (JBI) Evidence-Based Healthcare Database, DynaMed, Trip, Campbell, Elsevier, Cochrane Library, EBSCO, CINAHL, Embase, PubMed, OVID, China National Knowledge Infrastructure (CNKI), China Biomedical Literature Database (CBM), VIP Database, Wanfang Database. The English search terms include "pneumatic tourniquet, * tourniquet, air pressure hemostasis instrument, vascular occlusion and vascular block. The search query in English databases like PubMed, using a combination of controlled vocabulary and free-text terms, is as follows: ("tourniquet"[Mesh] OR "*tourniquet"[Ti/Ab] OR "air pressure hemostasis instrument"[Ti/Ab] OR "vascular occlusion"[Ti/Ab] OR "vascular block"[Ti/Ab]) AND ("Indications"[Ti/Ab] OR "contraindications"[Mesh] OR "preoperative Assessment"[Ti/Ab] OR "cuff selection and position"[Ti/Ab] OR "Exsanguinate the extremity" [Ti/Ab] OR "pressure setting" [Ti/Ab] OR "time setting" [Ti/Ab] OR "inflation" [Ti/Ab] OR "inflation monitoring" [Ti/Ab] OR "deflation"[Ti/Ab] OR "complications prevention" [Ti/Ab] OR "maintenance" [Ti/Ab]). The search period covered the time from the establishment of the databases until September 30, 2023.

Inclusion and exclusion criteria for literature

Inclusion Criteria: (1) Studies involving patients undergoing limb surgery who use pneumatic tourniquets during the procedure. (2) Studies focusing on measures related to the safe use of pneumatic tourniquets and prevention of complications. (3) Study types including clinical decisions, systematic reviews, evidence summaries, guidelines, and expert consensus. (4) Studies available in both Chinese and English.

Exclusion Criteria: (1) Studies involving the use of pneumatic tourniquets for pre-hospital emergency hemostasis in patients. (2) Incomplete or inaccessible information, duplicate publications. (3) Interpretations or translated versions of foreign guidelines, non-latest or abbreviated versions of guidelines. (4) Studies judged to be of low quality according to the literature quality assessment criteria.

Literature quality assessment

Four researchers independently assessed the included guidelines, and two researchers independently assessed the quality of expert consensus, standard and systematic reviews. In cases of conflicting opinions, resolution was achieved through negotiation or the involvement of a third researcher. All four researchers have received systematic training in evidence-based methodology. When conflicting conclusions arise from different sources of evidence, selection is guided by the principles of prioritizing high-quality evidence, evidence-based findings, and the most recently published authoritative literature. The Criteria for Literature Quality Assessment as follows:

(1) The quality of guidelines related to the safe use of pneumatic tourniquets was assessed using the Appraisal of Guidelines for Research and Evaluation II (AGREE II) system [15]. This assessment system consists of six domains (23 items) and two overall assessment items. Each item is scored from "completely not met" to "completely met", with scores ranging from 1 to 7. The sum of scores for all items in each domain is calculated, and this score is then standardized as a percentage of the maximum possible score for that domain. The standardized scores determines the quality of the guideline, and this study excludes Level C literature.
(2) The original literature that traces clinical decisions and evidence summaries is initially assessed based on the type of original research. For the identified literature, quality assessments are conducted using the appropriate assessment tools, including the JBI Critical Appraisal Checklist for Case Series and Systematic Reviews [9].
(3) Expert consensus and standards are assessed using the JBI Expert Consensus Assessment Criteria (2017 version) [16], which comprises six items and is rated as "yes", "no", "unclear", or "undetermined".
(4) Systematic reviews are evaluated for quality using the AMSTAR 2 (A MeaSurement Tool to Assess systematic Reviews) criteria (2017 version) [16], consisting of 16 items. Ratings are categorized as "yes", "partial yes", or "no" to grade the quality of the systematic review as "high quality", "moderate quality", "low quality", or "critically low quality".

Evidence extraction, integration, and summarization

Two researchers independently conducted evidence extraction focusing on key aspects of pneumatic tourniquet use. The extracted information included publication date, study type, source of evidence, evidence topic, and specific content. The process of translating, extracting, and integrating evidence involved the participation of all researchers. Principles of evidence integration: (1) When evidence content is consistent, prioritize evidence that is concise, clear, and professionally oriented. (2) When evidence content complements each other, merge the evidence into logically structured statements. (3) When there are differences in evidence content, prioritize evidence based on the principles of evidence-based, high-quality, authoritative, and recently published evidence. In this study, four researchers were divided into two groups to evaluate the original literature included in the evidence based on the JBI Evidence Pre-grading and Recommendation Grading System (2014 version) [16]. In cases of disagreement, all four members discussed and made a decision. The evidence was categorized from "highest level" to "lowest level" based on the type of original research and further classified into levels 1–5. Recommendations were divided into strong recommendations (Grade A) and weak recommendations (Grade B) based on evidence applicability, feasibility, effectiveness, and clinical significance.

Results

General characteristics of included literature

This study included a total of 13 articles, comprising 2 clinical decision articles [17, 18], 3 guidelines [19–21], 5 expert consensus papers [22–26], 1 standard [27] and 2 systematic reviews [9, 28]. The literature selection process is illustrated in Fig. 1, and the general characteristics of the included literature are presented in Table 1.

Literature quality assessment results

Quality assessment results for clinical decision-making

In this study, a total of 2 clinical decision articles were included, and tracing their original literature resulted in 1 cohort study [29] and 2 systematic reviews [30, 31]. Regarding the study by Olivecrona et al. [29], except for the item 'Whether the description of the absence of outcome measures in the study population at exposure or at the beginning of the study is unclear', which was rated as 'unclear', all other items were rated as 'yes'. Therefore, this literature was of high quality and was included. As for the studies by Alcelik et al. [30] and Zhang et al. [31], the quality assessment results are presented in Table 2.

Quality assessment results of the guidelines

This study included a total of 3 guidelines [19–21]. The standardized percentage scores for each domain and the overall assessment opinions are presented in Table 3.

Quality assessment results for expert consensus and standard

This study included a total of 5 expert consensus [22–26] and 1 standard [27] articles. The quality of these

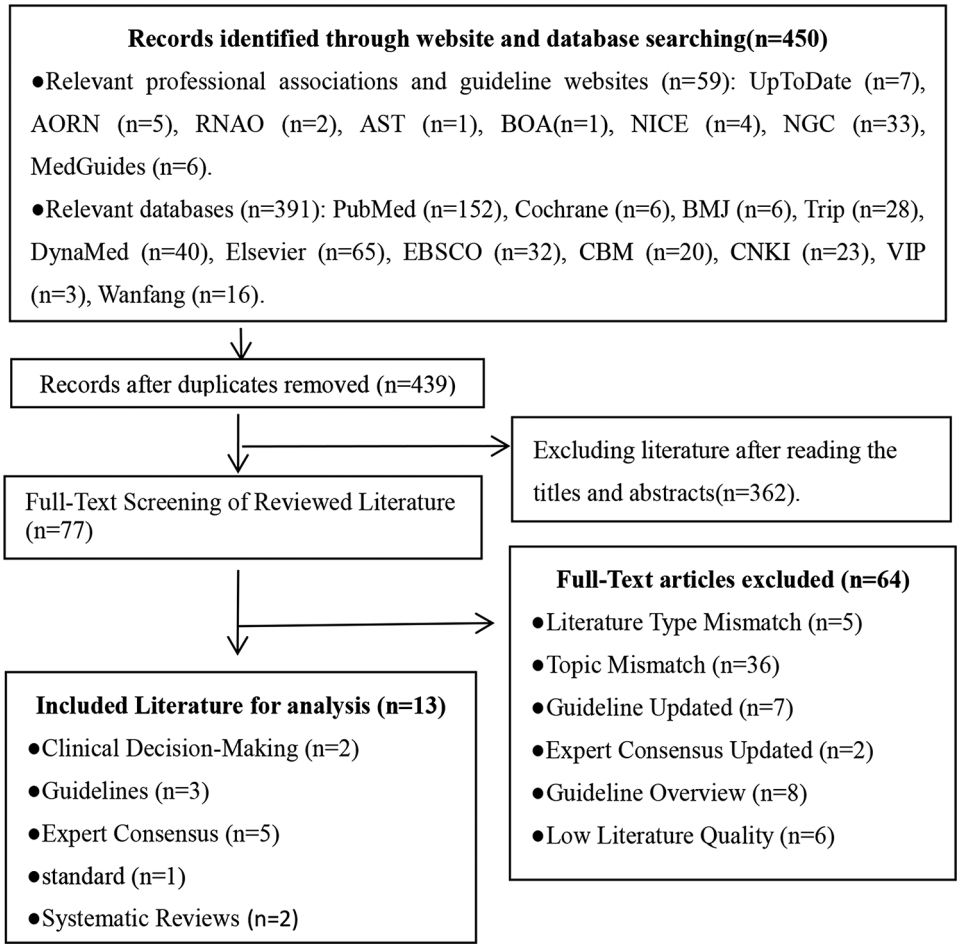

Fig. 1 Literature screening workflow

articles was high, with all criteria evaluated as "yes", and they were included in the analysis.

Quality assessment results of systematic reviews

This study included 2 systematic reviews [9, 28]. The quality assessment results are presented in Table 2.

Evidence summary

In this study, we have summarized 34 items of best evidence from 10 aspects, including indications and contraindications for the application of pneumatic tourniquets, operator preoperative evaluation, selection and placement of tourniquet cuffs, tourniquet inflation, monitoring during inflation, tourniquet deflation, common complications and prevention, equipment safety, documentation, training and education. Please refer to Table 4 for details.

Discussion

Clarify the indications and contraindications for the use of pneumatic tourniquets, and improve the preoperative evaluation process for operators

Currently, there is ongoing controversy over the effectiveness of using pneumatic tourniquets due to postoperative complications in patients. Before using a pneumatic tourniquet, enhancing preoperative evaluation content and accurately identifying suitable patients are prerequisites for reducing postoperative complications and ensuring patient safety. High-quality evidence recommends that surgical patients who meet the indications for pneumatic tourniquets should use this device as much as possible for hemostasis [19, 20, 22]. This study aimed to provide clear guidelines on the indications and contraindications for pneumatic tourniquet use, thereby aiding clinicians in making informed decisions to enhance patient safety and reduce complications. There is still controversy over whether patients undergoing knee replacement surgery should use pneumatic tourniquets. Proponents argue that intraoperative pneumatic tourniquet use can provide a bloodless surgical field, enhance the operating

Table 1 General characteristics of included literature ($n = 13$)

Author	Source	Type	Topic	Publication Year
Adam et al. [17]	UpToDate	Clinical Decision-Making	Inflation Monitoring of Pneumatic Tourniquets in Anesthesia for Total Knee Arthroplasty	2023
Gregory et al. [18]	UpToDate	Clinical Decision-Making	Inflation Monitoring of Pneumatic Tourniquets in Total Knee Arthroplasty"	2023
Jiangsu Province Orthopaedic Association, Jiangsu Society of Physical Medicine and Rehabilitation, Jiangsu Association of Rehabilitation Medicine, Xuzhou Orthopaedic Association [24]	CNKI	Expert Consensus	Jiangsu expert consensus of all-inside anatomical repair of anterior talofibular ligament for chronic lateral ankle instability based on enhanced recovery after surgery program	2022
AORN [19]	AORN Website	Guideline	Pneumatic Tourniquet Safety Guidelines	2021
BOA [27]	BOA Website	Standard	The Safe Use of Intraoperative Tourniquets	2021
Expert Consensus on Application of Pneumatic Tourniquet in Limb Operation Collaboration Group [22]	CNKI	Expert Consensus	Expert Consensus on application of Pneumatic Tourniquets in patients undergoing Limb operation	2020
Partial Knee Arthroplasty Group of Joint Surgery Professional Committee in Chinese Research Hospital Association [25]	CNKI	Expert Consensus	Expert consensus on perioperative management of unicompartmental knee arthroplasty	2020
The Emergency Physicians Branch of the Chinese Medical Association [26]	CNKI	Expert Consensus	The Application of Tourniquets in Emergency Scenarios: Expert Consensus on Tourniquet Use During Elective Limb Surgery	2020
Ding et al. [9]	PubMed	Systematic Review	Individualized Pressure Settings of Pneumatic Tourniquets in Orthopedic Limb Surgery: A Meta-Analysis of Efficacy	2019
Trauma Orthopedics Professional Committee, Bethure Charitable Foundation; Traumatic Orthopedics Group, Society of Enhanced Recovery After Surgery, China International Exchange and Promotion Association for Medical and Health Care [23].	CNKI	Expert Consensus	Expert consensus on optimal treatment of distal radius fractures in line with the concept of enhanced recovery after surgery	2019
AST [20]	AST Website	Guideline	Best Practices Guidelines for the Safe Use of Pneumatic Tourniquets	2018
McGrory et al. [21]	PubMed	Guideline	Complications and Prevention Related to Pneumatic Tourniquets in Evidence-Based Clinical Practice Guidelines for Surgical Treatment of Knee Osteoarthritis	2016
Yi et al. [28]	PubMed	Systematic Review	The Application of Pneumatic Tourniquets in Total Knee Arthroplasty: A Meta-Analysis	2014

Note CNKI (China National Knowledge Infrastructure) is the most authoritative and comprehensive literature database in China, with the largest collection of journals and the highest number of documents

AST Association of Surgical Technologists, *BOA* British Orthopaedic Association

area, reduce surgical time, facilitate prosthesis implantation, and extend prosthesis longevity [32–34]. Opponents contend that using pneumatic tourniquets can increase overall intraoperative blood loss and hidden blood loss, resulting in more postoperative complications for patients [35, 36]. The reason this study included knee arthroplasty in the indications for pneumatic tourniquet use is primarily due to its role in providing a bloodless surgical field and an optimal operating area. However, in the past, only a limited number of studies provided a simple evaluation of this effect, without quantitative assessment. Additionally, most studies in the past focused on various postoperative complications that did not significantly impact the long-term outcomes of knee arthroplasty [37]. This is also the reason why joint surgeons still routinely use this device for hemostasis during surgery, given the increasing frequency of complications related to pneumatic tourniquets. For patients with relative contraindications, operators should heighten their awareness of risk assessment and thoroughly evaluate the factors associated with tourniquet-related complications. For example, in patients over 60 years old, the use of a tourniquet should be approached with caution due to the increased risks of delayed postoperative limb muscle recovery, muscle atrophy, and pulmonary embolism. Additionally, the risk of neurological complications, such

Table 2 AMSTAR 2 scores of included systematic reviews

Items	Alcelik et al. [30]	Zhang et al. [31]	Ding et al. [9]	Yi et al. [28]
1. Did the research questions and inclusion criteria for the review include the components of PICO?	Yes	Yes	Yes	Yes
2. Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?	Yes	Yes	Yes	Yes
3. Did the review authors explain their selection of the study designs for inclusion in the review?	Yes	Yes	Yes	Yes
4. Did the review authors use a comprehensive literature search strategy?	Yes	Yes	Yes	Yes
5. Did the review authors perform study selection in duplicate?	Yes	Yes	Yes	Yes
6. Did the review authors perform data extraction in duplicate?	Yes	Yes	Yes	Yes
7. Did the review authors provide a list of excluded studies and justify the exclusions?	Yes	Yes	Yes	Yes
8. Did the review authors describe the included studies in adequate detail?	Yes	Yes	Yes	Yes
9. Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?	Yes	Yes	Yes	Yes
10. Did the review authors report on the sources of funding for the studies included in the review?	No	No	No	No
11. If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?	Yes	Yes	Yes	Yes
12. If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?	Yes	Yes	Yes	Yes
13. Did the review authors account for RoB in individual studies when interpreting/ discussing the results of the review?	Yes	Yes	Yes	Yes
14. Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	Yes	Yes	Yes	Yes
15. If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	Yes	Yes	Yes	No
16. Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	No	No	Yes	No

as nerve damage, increases by approximately 0.7 times for every 10-year increase in age, particularly when tourniquet inflation exceeds 120 min [19]. Operators should also carefully assess the risks in pediatric patients [22], those with an increased risk of venous thromboembolism (VTE), and those with low preoperative hemoglobin levels. In patients with a high body mass index (BMI), especially those with a BMI > 30 kg/m², the use of a tourniquet should be cautiously considered due to the increased risks of delayed functional recovery, postoperative limb swelling and pain caused by higher inflation pressures, and an elevated risk of pulmonary embolism [19–20, 22]. Meanwhile the operator should complete the preoperative assessment include tourniquet type, size, placement, and pressure settings, etc. [20]; Evaluate pulse, temperature, capillary refill, condition of the distal skin, sensory of the patient's limb and motor responses compared between both limbs [19]; Assess whether the patient has a history of local anesthetic allergies [20]; check with a surgeon or anesthesiologist to ensure the safety of use, especially for patients at risk of complications. During the operation, tourniquet operators should also strengthen communication with the doctor and pay attention to the patient.

Proper selection of tourniquet cuffs and placement locations, and individualized setting of inflation pressure and time

Selecting the correct tourniquet cuff size, and shape, placing it in the optimal position can help maintain pressure consistency, visibility, and cuff fit, reduces potential complications such as skin damage, and is beneficial for patient safety [19]. One of the primary objectives of this study was to provide a framework for the appropriate selection of tourniquet cuffs and the individualized setting of inflation pressure, which are crucial steps in minimizing complications and ensuring effective hemostasis during surgery. All existing evidence recommends selecting an appropriate type and model of cuff based on the patient's limb circumference and shape [19, 20, 22]. Encountering obese or muscular patients during surgery, the cuffs cover the body in a conical shape, the use of a straight cuff may lead to uneven pressure distribution across the cuff, with excessive pressure concentrated at positions with a larger limb circumference, to some extent, it will increase the risk of injury in this area. In contrast, contour cuffs can reduce excessive pressure on local limb areas, significantly lowering the cuff pressure required for vascular occlusion in both adults and children [20].

Table 3 Methodological quality assessment of included guidelines

Guidelines	Standardization Percentage for Each Field (%)						Overall Quality Rating of the Guideli-nes (scores)	Recom-menda-tion for Using This Guideline	≥ 60% Number of Fields	≥ 30% Number of Fields	Recom-menda-tion Level
	Scope and Purpose	Participants	Rigor of Formu-lation	Clarity	Applicabi-lity of theGuidel-ines	Indepe-ndence of Editing					
AORN [19]	94.44	86.11	77.60	97.22	75.00	89.58	6	YES	6	6	A
AST [20]	84.72	75.00	50.00	95.83	22.92	29.17	4	YES	3	4	B
McGrory et al. [21]	98.61	97.22	88.54	94.44	85.42	100	6	YES	6	6	A

Before inflating the cuff, blood removal from the limb can help create a relatively bloodless surgical area, however, currently there is no unified standardized method for limb blood drive, and most of them use alternating squeezing with both hands to drive blood, especially when deflation and reinflation are required. Related studies [19] have indicated that compared to using elastic bandages, alternating squeezing with both hands to expel blood increases postoperative pain and the likelihood of tension induced blisters in patients. Therefore, it is recommended to use elastic bandages and raise the limbs to expel blood, For patients with recent plaster casts, infections, closed fractures, or malignancies, exsanguination can be achieved by elevating the arm to 90°or the leg to 45°for 5 min; for all other patients, an elastic bandage is suitable for exsanguination [19–20], sterile elastic bandages should be prepared for use during limb blood removal after deflation but before reinflation.

Regarding the initial pressure setting for the tourniquet, there is currently no national standard, most clinical applications are set to standard pressure. Ding [4] found that personalized pressure setting based on Limb Occlusion Pressure (LOP) significantly reduced the incidence of postoperative pressure related complications compared to standard pressure, while maintaining the same surgical time and field. High-quality evidence recommends setting personalized initial pressure, suggesting the preference of using LOP combined with limb circumference to add an appropriate margin for setting the initial inflation pressure. For patients who meet the criteria, setting the pressure based on systolic blood pressure (SBP) is also recommended.By focusing on the importance of personalized pressure settings, this study aims to establish a more reliable approach to tourniquet use, thereby improving surgical outcomes and reducing the risk of pressure-related injuries. Currently, there is a lack of research on the establishment of safety margin parameters, further high-quality randomized controlled trials with large sample sizes and multiple centers are needed in the future.

Follow and Monitor the Operation Procedure of Pneumatic Tourniquets, keep good records of usage monitoring and prevention and treatment of complications

Relevant studies have found that prolonged with inflation time, the incidence of postoperative complications will significantly increase. For every 30-minute increase in inflation time, the risk of nerve injury triples [20]. Additionally, inflation times exceeding 100 min can lead to increased patient discomfort [17]. High-quality evidence [17–20, 22–24] recommends minimizing inflation time, strictly adhering to the operation procedure, timely detection of equipment malfunctions and operational errors to avoid patient injury [38]. The purpose

Table 4 Summary of best evidence for the safe use of pneumatic tourniquets in limb surgery

Category	Evidence Content	Evidence Level	Recommendation Level
Indications and Contraindications	1.Indications [19, 22]: Applicable for procedures such as fracture fixation, limb deformity correction, soft tissue mass excision, wound debridement, tendon repair, amputations, hemostasis in open limb injuries, and joint surgeries (e.g., knee, ankle, elbow, wrist).	5	A
	2. Absolute contraindications [19, 20, 22]: Patients with a history of skin grafts, dialysis access, prior vascular reconstructions, multiple digit or toe reconstructions following trauma, severe hypertension of grade III, and intracranial hypertension.	1	A
	3. Relative contraindications [19, 20, 22]: Patients with peripheral vascular disease (PVD), sickle cell anemia, severe crush injuries, diabetic neuropathy, a history of malignant tumors or pulmonary embolism, acidosis, severe infections, open fractures, significant scar tissue at the cuff site, or thigh circumference >100 cm.	3	B
Preoperative Assessment	4. Preoperative Planning [19–20, 22]: Surgeons or anesthesiologists create a usage plan based on the patient's medical history, physical condition, type and duration of the surgery.	5	A
	5. Risk Assessment [19–20, 22]: Before the operation, the operator should be familiar with the tourniquet plan and assess risk factors such as advanced age, pediatric status, increased thromboembolism (VTE) risk, low preoperative hemoglobin, and high body mass index (BMI). Additionally, evaluate the limb condition and check for any history of local anesthetic allergies.	2	B
Selection and Placement of Tourniquet Cuffs	6. System Check and Cuff Selection [19–20, 22]: Test the tourniquet system for leaks or malfunctions, and choose the appropriate cuff type and size based on the patient's limb circumference and shape, following the manufacturer's guidelines.	2	A
	7. Preoperative Verification: Before using a pneumatic tourniquet and during the preoperative time-out, verify both the surgical and non-operative sides to ensure the tourniquet is correctly placed [19–20].	5	A
	8. Cuff Placement: Position the cuff at the point of maximum limb circumference [20–22], If placed on the calf, ensure the cuff's edge is at least 2–4 cm distal to the fibular head and 2 cm above the ankle [20]. For pediatric patients, consider placing the cuff on the most proximal part of the limb [20].	4	A
	9. Skin Protection: Use elastic sleeves or low-lint padding to protect the skin at the cuff site. Secure the cuff with reverse wrapping and employ physical barriers like waterproof drapes to prevent fluid accumulation and contamination [19–20, 22–24].	2	A
	10. Cuff Repositioning: When repositioning the cuff, replace the padding and re-wrap to avoid sliding or rotating the cuff [19–20].	4	A
	11. Tubing and Connector Safety: Use cuffs, tubing, and connectors that are incompatible with other lines, and clearly label them [19]. Place the connecting tubing on the outer side of the limb, away from sterile areas and high-traffic zones, to prevent occlusion and ensure unobstructed flow [19–20].	5	A

Table 4 (continued)

Category	Evidence Content	Evidence Level	Recommendation Level
Tourniquet Inflation	12. Exsanguination Before Inflation: Before inflating the tourniquet cuff, achieve exsanguination by using an elastic bandage or elevating the limb, and inform the surgical team. Avoid alternating manual compression with both hands [19, 20, 23, 24]. Intraoperatively, use a sterile elastic bandage to re-establish exsanguination before reinflating the cuff [19–20].	4	A
	13. Tourniquet Pressure Setting: The recommended approach for tourniquet pressure setting is initially preferably base on Limb Occlusion Pressure (LOP) in conjunction with limb circumference, Alternatively base on Systolic Blood Pressure (SBP) [9, 19, 20, 22]. while for pediatric patients, it is advisable to use wide contour cuffs and set the inflation pressure based on LOP [20, 22].	1	B
	14.Measurement of SBP and LOP [19, 20, 22] : Obtaining baseline readings before or after the induction of anesthesia, when the patient's blood pressure has stabilized at the expected level. The determination of LOP can be achieved using Doppler ultrasound or pulse oximetry monitoring as follows: (1) Doppler Ultrasound: For lower limb surgeries, scan the popliteal area vertically over the femur before inflating the tourniquet. Identify the popliteal artery pulse, then slowly inflate the tourniquet cuff. LOP is the cuff pressure at which the popliteal artery pulse disappears on the ultrasound, with no blood flow visible in color Doppler mode. (2) Pulse Oximetry: Attach a pulse oximeter probe to a finger or toe of the limb being operated on. Gradually inflate the tourniquet cuff. LOP is the cuff pressure at which the arterial waveform on the pulse oximeter monitor flattens into a straight line.	1	B
	15.Pressure Setting Guidelines: (1) For LOP-Based Tourniquets Pressure Setting [20, 22, 23]: (a) Pressure should not exceed 500 mm Hg; (b) When LOP is < 130 mm Hg, set inflation pressure at LOP + 40 mm Hg; (c) When LOP is between 131–190 mm Hg, set inflation pressure at LOP + 60 mm Hg; (d) When LOP is > 190 mm Hg, set inflation pressure at at LOP + 80 mm Hg; (e) For pediatric patients, set inflation pressure at LOP + 50 mm Hg; (2) For SBP-Based Tourniquets Pressure Setting: For upper limbs, set the initial pressure at SBP + 50 mm Hg [19, 22], and for lower limbs, set the initial pressure at SBP + 100 mm Hg [20, 22]. When using multiple cuffs on the same limb, or for obese patients or limbs with larger circumferences [19, 22], it may be necessary to appropriately increase the inflation pressure [19].	2	B
	16.Identification and Confirmation: Clearly identify the cuff placement, corresponding tubes, and equipment. Confirm the inflation pressure and sequence with the surgeon or anesthesiologist before proceeding with rapid inflation [19–20, 24].	5	B
	17. Prophylactic Antimicrobial Administration [19–20]: Administer intravenous antimicrobial agents 30 min before incision and 10 min before inflating the tourniquet to ensure optimal drug concentrations.	2	A
Monitoring During Inflation	18.Inflation Duration: (1) General Guidelines: For upper limbs, set the tourniquet inflation time to 60 min, and for lower limbs, 90 min. The maximum recommended duration is 120 min, with a preferable limit of 100 min [17–20, 22–24]. In certain cases, following a clinical assessment of risks and benefits by the surgeon, inflation time may extend beyond 120 min but should rarely exceed 150 min [27]. (2) Pediatric patients: The recommended inflation time for both upper and lower limbs is 60 min [20], with a maximum limit of 75 min [19]. (3) Interval Between Applications [20–24]: Allow a 10–15 min interval between successive tourniquet applications for both upper and lower limbs. The repeat inflation time should not exceed 60 min, with a reduction in time for each subsequent application.	1	A
	19. Monitoring for Complications [19–20]: Regularly check inflation pressure and duration to monitor for tourniquet-related complications, particularly during surgical repositioning of the limb.	3	A
	20. Visibility and Audibility: Maintain pressure displays and activation indicators visible to the entire surgical team, with alarm sounds set higher than other noises in the operating room [19].	5	A
	21. Inflation Time Alerts: It is advisable to inform the surgeon of the tourniquet inflation time every 15 min after the first hour of inflation [19, 23], and every 10 min beyond 120 min [27].	5	A

Table 4 (continued)

Category	Evidence Content	Evidence Level	Recommendation Level
Tourniquet Deflation	22. Deflation Coordination: Before deflating the tourniquet, the operator should communicate with the surgeon and anesthesiologist to establish the timing and sequence of deflation [19]. When deflating tourniquets on both limbs simultaneously, the interval should be at least 10–15 min [22].	1	B
	23.Postoperative Management: It is strictly prohibited to perform plaster fixation procedures before deflation [19]. After surgery, promptly remove the tourniquet and padding [19–20, 22], and never dismantle them while they are inflated [22].	5	A
	24. Post-Tourniquet Evaluation: Evaluate and compare the condition of the limb's skin, neurological integrity, and limb reperfusion before and after tourniquet use [19]. Monitor patient vital signs and the skin temperature of the operated limb [19, 22, 24], maintain normal respiratory levels [20], and assess tourniquet-related pain following deflation [19].	4	A
	25.Postoperative Handover [19]: During the postoperative handover, provide a comprehensive assessment of the patient, including both preoperative and postoperative evaluations, as well as details of the tourniquet intervention.	5	A
Common Complications and Prevention	26. Complications [21–22]: Decreased muscle strength, muscle swelling, and atrophy; skin, vascular, and nerve injuries; tourniquet related burn; increased postoperative pain; changes in the internal environment such as lactic acidosis and hyperkalemia; deep vein thrombosis or pulmonary embolism; ischemia-reperfusion injury; fluctuations in core body temperature, and others.	1	A
	27. Prevention and Management of Complications: (1) Conduct a comprehensive preoperative assessment of the patient's condition, accurately determine indications and contraindications, establish appropriate pressure and time settings, adhere to standardized procedures, enhance monitoring, and reduce the occurrence of related complications [22]. (2)Finger or toe tourniquets should be highly visible or applied using instruments included in the surgical instrument count so that they cannot be inadvertently retained [27]。 (3) Ensure immediate availability of necessary medications in case of complications [20] and actively assist the physician in resuscitation and treatment efforts [22].	5	B
Device Safety	28. Multidisciplinary Team Involvement: A multidisciplinary team should be involved in the selection and procurement of tourniquet systems to ensure that the equipment meets the specific surgical requirements of the procedure [20].	5	B
	29. Routine Inspection and Maintenance: Incorporate pneumatic tourniquets into the routine equipment inspection and maintenance schedule, with dedicated personnel responsible for regular upkeep, monitoring, and proper documentation [19–20, 22].	5	A
	30. Cleaning and Disinfection: For reusable cuffs and bladders, clean and disinfect them with an alcohol solution or an EPA-registered intermediate-level disinfectant. Dry and perform leak testing before storage. If a cuff cannot be adequately cleaned, it should be discarded. Disposable tourniquet cuffs should not be reused [19–20, 22].	5	A
	31.Response to Complications: In the event of patient injury or the occurrence of related complications, cease tourniquet use immediately and notify the surgical team [19]. Document the patient's symptoms, as well as the start and stop times of tourniquet application [20]. Retain all materials and report the details of adverse events [19].	5	A
Document Records	32.Documentation: Document the pre- and post-operative limb assessment, as outlined in references [19–20, 22]. Additionally, record details about the usage of pneumatic tourniquet and system identification information [19–20, 22]. Record the method of isolation used to exclude skin preparation fluids from seeping under the tourniquet [27].	5	B
	33.Adverse Event Recording: Record any adverse events that occur. In the event of an adverse incident, provide a comprehensive account of the incident's sequence of events, the actions taken in response, and potential contributing factors [22].	5	A
Education and Training	34. Education and Training: Provide education on the use of pneumatic tourniquets, including instructions for use, system settings [20], contraindications, physiological impacts on patients, patient risks, and preventive measures, selection of cuffs, safe use of tourniquets and accessories, initial pressure settings, safety margin measurement, relevant complications, and preventive measures [19–20], as well as safety precautions specific to Intravenous Regional Anesthesia (IVRA) [19].	5	A

of this study also includes reinforcing the adherence to operational procedures and ensuring meticulous monitoring during the use of pneumatic tourniquets, which is essential for preventing complications and enhancing patient safety. Rapid deflation of the tourniquet can result in a significant influx of blood into the limbs, causing a sharp drop in blood pressure reduction and potentially leading to hypovolemic shock. Therefore before deflating

the tourniquet, the operator should communicate with the surgeon and anesthesiologist ensure the systolic blood pressure is above 90 mmHg, otherwise rapid volume replacement and, if necessary, vasopressor administration should be performed before deflation. And also during deflation, the limb should be slowly lowered [22]. Additionally, rapid deflation can introduce metabolic byproducts from ischemic limbs into the bloodstream, such as lactate, to alter the body's internal environment and cause ischemia-reperfusion injury. Therefore, it is essential to deflate slowly, strictly prohibit removing the tourniquet without prior deflation, and monitor the patient's vital signs during deflation, maintaining them within the normal range to ensure patient safety [39]. Proactive prevention of complications and effective management of related adverse events should also be emphasized. If a tourniquet related burn [27] is suspected in the operating theatre, we should detail the documentation of the site and dimension of the injury, skin preparation fluid and duration of contact, digital photography, upload the patient record, and then discuss with a plastic surgical and/or tissue viability team. If a tourniquet related burn is confirmed, an ongoing management plan should be documented, which must include shared decision making with a plastic surgical and/or tissue viability team.

Regular maintenance, reasonable recording of usage, strengthening education and systematic training for medical staff

As a routine hemostatic instrument used in limb surgery, if a malfunction occurs during use, it will seriously affect the hemostatic effect and patient safety. Therefore, pneumatic tourniquets should be included in the department's instrument and equipment maintenance plan, with regular maintenance by dedicated personnel and proper calibration of pressure settings to ensure the integrity and functional excellence of the equipment and its accessories.This study aims to underline the importance of regular maintenance and systematic training for medical staff to prevent operational errors and ensure the continued safe use of pneumatic tourniquets in clinical practice. In addition, as a potential source of postoperative infection for patients [40], Cultures of tourniquets demonstrated colonisation with bacteria and fungi most of the isolates belonged to the normal flora of the skin and staphylococci formed the predominant isolate, which is the most common organism that causes deep wound infection [41]. In clinical practice surgeons always place cuff on the operative limb of the patient without gloves, after anesthesia induction and prior to hand hygiene. And then prepare the limb for antisepsis till the cuff was draped with sterile sheets.Although sterile drapes preclude the cuff from contacting with the operating field, but the passage of bacteria through fabrics has been identified more so when the fabric is moist. The Association of Operating Room Nurses (AORN) has recommended that Clean and disinfect reusable cuffs and bladders after each use with a facility-approved disinfectant in accordance with the manufacturer's IFU [19], which were 90% effective in reducing tourniquet contamination [42]. Therefore in our clinical practice pneumatic tourniquets requires cleaning, disinfection, and proper storage of reusable cuffs to avoid cross infection between patients caused by cuffs. For cuffs that cannot be thoroughly cleaned, they should be discarded directly and the reuse of disposable cuffs is prohibited. During the use of pneumatic tourniquets, medical staff should keep relevant records encompass the evaluation of skin condition, vascular integrity, neurological and muscular functions, sensory responses, and limb occlusion pressure. Additionally, record details such as cuff size and placement, operator information, skin protection measures, pressure settings, inflation and deflation times, total inflation time, initial blood pressure post-inflation, reperfusion time, systemic responses to ischemia and reperfusion, communication regarding critical observations (i.e., recipients, content, and timing), and system identification information [19–20, 22]. These records can help us timely and effectively handover with the patient's postoperative recovery team, and provide comprehensive nursing services for patients. If an adverse event occurs, medical staff should promptly and in detail record the event process, such as time, type, symptoms, and possible causes of malfunction. All materials should be retained as much as possible, and details of the adverse event should be reported according to the policies and procedures of the medical institution, including equipment identification, maintenance, and usage information.

The AORN "Pneumatic Tourniquet Safety Guideline" recommends systematic training for interdisciplinary teams, risk management personnel, anesthesiologists, surgeons, perioperative nurses, and other personnel involved in auxiliary procedures, including perioperative leaders [43], to enrich the theoretical knowledge of team members and enable them to proficiently master operational skills, This can effectively prevent and calmly deal with various problems that may arise during the use of pneumatic tourniquets. At present, there is limited literature on training related to the operation of pneumatic tourniquets. In the future, targeted safety education on the use of pneumatic tourniquets should be based on the knowledge, attitudes, and practices of orthopedic surgical staff [44]. This includes standardized training in preoperative assessment, equipment operation, intraoperative monitoring, postoperative patient observation and documentation. Enhancing awareness of the risks associated with pneumatic tourniquet use and improving

operational proficiency and accuracy are crucial to preventing adverse events. The structured risk management approach for surgical errors by Houben and Pascher [45] can be adapted through simulation training and case sharing to promote growth among personnel involved in tourniquet use, thereby reducing operational errors. Additionally, the cognitive training model proposed by Anderson et al. [46] can be referenced to enhance the skills and knowledge base of medical staff. Specialized training for pneumatic tourniquet operators should focus on the selection, placement, fixation of cuffs for different patients, pressure settings as well as adjustments through visual-tactile simulation training [47] and computer-assisted training [48] to finish the entry-level training and assessments. Regular training sessions should be held to address changes in tourniquet brands and models, ensuring that operators are proficient and minimizing errors due to the variety of tourniquet types.

Limitation

Although this study comprehensively summarized the evidence on the safe use of pneumatic tourniquets in patients undergoing limb surgeries, the study results may be affected by different regional, racial and cultural background. Furthermore, we only searched English and Chinese databases without literature published in other languages in this study. In future studies these evidence should be continuously updated, and appropriate evidence should be selected based on the suitability, feasibility, effectiveness and clinical practice to enhance the implementation of such evidence.

Conclusion

This study summarizes the best evidence for the safe use of pneumatic tourniquets in patients undergoing limb surgeries from 10 aspects 34 items. This can provide reference for clinical medical staff to safely use pneumatic tourniquets, but as the evidence comes from different countries, it is recommended to select and apply evidence in clinical practice based on the patient's own condition and the actual situation of the hospital. At present, there is still a lack of high-quality randomized controlled trials for the setting of personalized initial pressure and safety margin parameters. In the future, further research can be conducted to improve the safety and hemostatic effect of pneumatic tourniquets.

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Author contributions

Gy L contributed to the design of the work, the Literature acquisition, analysis and paper writing. Ly X, Xt Z, MT contributed to the Literature acquisition, analysis and interpretation of data. JM M supervised the writing of and revision of the manuscript. All authors read and approved the final manuscript.

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Data availability

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

Declarations

Ethics approval and consent to participate

This study primarily relies on literature search and screening to extract relevant evidence, which is then summarized and integrated. Since the research process does not involve animals or humans, ethical review was not required. This was confirmed by the Shandong Provincial Hospital Biomedical Research Ethics Committee involving humans.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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