Advances in the Management of Acute Limb Ischemia: A Comprehensive Review of Current Strategies and Techniques

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ABSTRACT

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| **Aims:** The purpose of this study is to review and summarize the latest management strategies of ALI, including the role of endovascular engineering, reconstructive surgery, and pharmacological therapy.  **Study design:** This study is a comprehensive literature review analyzing recent clinical guidelines, empirical studies, and current strategies in the management of Acute Limb Ischemia (ALI). The review focuses on evaluating the effectiveness of endovascular, surgical, and pharmacological interventions.  **Place and Duration of Study:** The review encompasses literature and clinical guidelines published up to 2024, including data from leading cardiovascular and vascular surgery centers internationally, with a focus on practices relevant to hospitals such as dr. Sosodoro Djatikoesomo Hospital and dr. Saiful Anwar Hospital in East Java, Indonesia.  **Methodology:** The methods used were a comprehensive literature review of current clinical guidelines and empirical studies related to the management of ALI.  **Results:** The results show that endovascular therapies such as directed thrombolysis and mechanical thrombectomy are increasingly preferred because they are minimally invasive with a high success rate, while bypass surgery procedures remain important in cases of severe ischemia and failure of endovascular therapy. A multidisciplinary approach and quick treatment are the keys to the success of therapy.  **Conclusion:** In conclusion, ALI management must integrate modern techniques and collaboration between specialists to improve limb rescue rates and reduce serious complications. |

*Keywords: Acute Limb Ischemia, Management, Surgical Revascularisation, Endovascular Treatment.*

1. INTRODUCTION

Acute Limb Ischemia (ALI) is defined by an abrupt reduction in arterial perfusion to the limb, posing a possible risk to limb viability, necessitating immediate assessment and intervention. ALI is diagnosed when symptoms persist for fewer than two weeks. 1 ALI jeopardizes limb viability within a brief timeframe, as there is inadequate time for the formation of new blood vessels to offset the reduction in perfusion (2,3).

Research indicates an incidence rate of 22-26 cases per 100,000 patients annually. 4 Complications in patients with acute limb ischemia (ALI) are significant, and despite prompt revascularization, the 30-day mortality and amputation rates range from 10% to 15%. ALI is a prevalent cause of significant amputation, impacting roughly 1.5 individuals per 10,000 year (5).

Furthermore, ALI patients encounter a heightened incidence of in-hospital severe adverse events, including myocardial infarction, worsening of congestive heart failure, deterioration of renal function, and respiratory problems.4,6 The aetiology of non-traumatic acute limb ischaemia can be classified as embolic (30%), thrombotic (60%), or thrombosis of a pre-existing stent or bypass graft. Potential embolic etiologies associated with an acute reduction in limb perfusion include the following: cardiac embolization, aortic embolization (perhaps resulting from a thrombosed aneurysm), thrombosed graft, ergotism, hypercoagulable syndromes, paradoxical venous-to-arterial embolism, and iatrogenic problems associated with endovascular procedures (2,3).

Upon suspicion of diagnosis, the degree of limb ischaemia must be assessed utilising the established classification system, developed by the Society for Vascular Surgery (SVS) and modified from the Rutherford classification (TASC II) (5,7). The abrupt ischemia impacts all metabolically active tissues in the limb: dermis, musculature, and neural structures. Consequently, immediate acknowledgment and swift revascularization are essential to maintain limb viability.

Acute limb ischemia (ALI) is a critical vascular emergency marked by the abrupt cessation of arterial blood flow to a limb causing decreased arterial perfusion of limb, leading to potential tissue necrosis, posing a possible risk to limb viability and limb loss if not promptly managed which necessitating immediate assessment and intervention. ALI is diagnosed when symptoms persist for fewer than two weeks (1).

ALI aetiologies can typically be classified as in-situ arterial thrombosis, embolism, or aneurysm, which may manifest as thrombosis or result in distal embolism.4,6 The predominant causes of ALI are embolism, thrombosis of native arteries or reconstructions, peripheral artery aneurysm, dissection, and traumatic arterial injury. There are also uncommon cause of acute limb ischaemia.1 The predominant causes of embolism encompass cardiogenic factors or a compromised artery adjacent to the impacted arterial region (e.g., unstable atherosclerotic plaque or aneurysm). Cardiac arrhythmias or dysfunctions, predominantly atrial fibrillation, myocardial infarction, or cardiac valve disorders, account for up to 80% of arterial embolism.

2. material and methods

**Bypass procedures**

According to the European Society for Vascular Surgery (ESVS) 2020 Clinical Practice Guidelines on the Management of Acute Limb Ischaemia (ALI), bypass surgery is a well-established open surgical revascularization technique used in acute limb ischemia (ALI) to restore blood flow when thromboembolectomy or endovascular therapies are insufficient or contraindicated.10 It involves creating an alternative conduit to bypass the occluded arterial segment, typically using autologous vein grafts. In cases of significant arterial disease or injury, bypass grafting with autologous veins or synthetic grafts can re-establish blood flow beyond the blockage. Bypass is typically utilised in instances where thrombectomy alone proves inadequate or when persistent arterial disease is present (3,48).

Scenarios in which rapid reperfusion is essential, particularly in Rutherford class IIb or III. Bypass surgery is warranted in acute limb ischaemia when lasting and effective revascularisation is necessary, particularly when alternative therapies are inappropriate or have proven ineffective. According to contemporary literature and clinical standards, the primary indications encompass

1. Failure or Contraindication of Catheter-Based Therapies:

When catheter-directed thrombolysis (CDT) or mechanical thrombectomy is contraindicated (e.g., due to hemorrhagic risk) or has proven ineffective in restoring sufficient perfusion, bypass surgery is deemed the subsequent option.

1. Extensive Arterial Occlusion Not Amenable to Endovascular Treatment:

Long-segment occlusions, extensively calcified arteries, or intricate architecture that obstructs endovascular access or success are grounds for bypass surgery.

1. Underlying Atherosclerotic Disease Requiring Durable Revascularization:

Patients with chronic atherosclerosis and acute occlusion often benefit from bypass to provide a long-lasting conduit, particularly when autogenous vein grafts are available.

1. Severe Limb Ischemia with Threatened or Non-Viable Limb:

In Rutherford class IIb or III ischemia, where rapid restoration of blood flow is critical to prevent limb loss, bypass may be preferred for immediate and durable reperfusion.

1. Urgent or Emergent Situations:

Bypass is indicated in urgent or emergent cases when limb viability is at risk and rapid, effective revascularization is necessary.

**Thromboendarterectomy and Patch Angioplasty**

Thromboendarterectomy and patch angioplasty are established open surgical techniques used in the management of acute limb ischemia (ALI), particularly when the ischemia is due to localized arterial thrombosis or atherosclerotic occlusion.

These procedures are typically considered when ALI is caused by thrombosis in a segment of a major artery (such as the common femoral artery), especially if there is underlying atherosclerotic disease or when thromboembolectomy alone does not restore adequate blood flow.

**Intraoperative Open Thrombolysis**

Intraoperative Open Thrombolysis is an adjunctive technique used during surgical intervention for acute limb ischemia (ALI), especially when mechanical removal of thrombus (embolectomy/thrombectomy) is incomplete or when there is distal thrombus that cannot be accessed with standard catheters.

Indications:

1. Residual thrombus after embolectomy or thrombectomy, particularly in distal vessels.
2. Distal embolization or “no-reflow” phenomenon, where blood flow remains compromised after proximal clot removal.
3. Complex/multilevel occlusions where both proximal and distal segments are affected.

This technique is used in the surgical management of acute limb ischemia when mechanical removal of a blood clot is incomplete or when there is significant thrombus in distal vessels. The procedure combines direct surgical access to the affected artery with both mechanical and pharmacological methods to restore blood flow.

**Primary Limb Amputation**

Primary limb amputation refers to the immediate surgical removal of a limb or part of a limb without attempting revascularization, typically performed when the limb is deemed nonviable or irreversibly ischemic at presentation. This decision is crucial to prioritize the patient's overall survival and prevent systemic complications from severe ischemia and reperfusion injury. Indication for primary limb amputation include:

1. Irreversible Ischemia (Rutherford Class III): Characterized by severe motor paralysis, profound sensory loss, limb stiffness, cyanosis, and signs of tissue necrosis such as irreversible purpura. At this stage, the limb is considered unsalvageable, and attempts at revascularization are futile and may increase morbidity and mortality.
2. Delayed Presentation: When ischemia duration is prolonged (generally beyond 6-8 hours), extensive tissue damage and risk of reperfusion injury increase, making amputation necessary to save the patient's life.
3. Severe Ischemia-Reperfusion Injury Risk: In cases of high occlusion with extensive ischemia, primary amputation may be preferred to avoid systemic complications like rhabdomyolysis, renal failure, and metabolic disturbances.
4. Failed Revascularization or Compartment Syndrome: If revascularization fails or severe compartment syndrome develops with irreversible muscle and nerve damage, secondary amputation may be required.

3. results and discussion

Recent advances in the management of acute limb ischemia (ALI) have significantly improved patient outcomes by enabling earlier diagnosis, more effective revascularization, and better limb salvage rates. The evolution of both endovascular and surgical techniques, along with adjunctive pharmacological therapies, has expanded the therapeutic armamentarium for clinicians.

**Endovascular Techniques**

Endovascular approaches have become increasingly favored due to their minimally invasive nature and rapid recovery times. Techniques such as catheter-directed thrombolysis, percutaneous mechanical thrombectomy, and aspiration thrombectomy have demonstrated efficacy in restoring perfusion, particularly in patients with contraindications to open surgery or those with significant comorbidities. The development of newer devices, including next-generation aspiration catheters and mechanical thrombectomy systems, has enhanced clot removal efficiency and reduced procedure times. Recent trials suggest that these approaches, when used in appropriately selected patients, offer limb salvage rates comparable to traditional surgery with lower morbidity.

**Hybrid and Surgical Approaches**

Despite the rise of endovascular therapy, open surgical intervention remains crucial, especially in cases of extensive thrombus burden, failed endovascular therapy, or when rapid revascularization is required. Hybrid procedures, which combine open and endovascular techniques, have shown promise in complex cases, allowing for tailored therapy based on anatomical and clinical factors. Advances in surgical techniques, including improved bypass graft materials and intraoperative imaging, have contributed to better outcomes and lower complication rates.

**Adjunctive Pharmacological Strategies**

The integration of antithrombotic and anticoagulant therapies has played a pivotal role in both acute management and prevention of recurrence. Novel oral anticoagulants and more targeted thrombolytic agents are being investigated for their potential to reduce bleeding risks while maintaining efficacy. Furthermore, peri-procedural management protocols have been refined to optimize patient safety and enhance revascularization success.

**Multidisciplinary and Patient-Centered Care**

There is growing recognition of the importance of multidisciplinary care involving vascular surgeons, interventional radiologists, and critical care teams. Early diagnosis, facilitated by improved imaging modalities such as duplex ultrasonography and CT angiography, allows for prompt intervention, which is critical given the narrow window for limb salvage in ALI. Additionally, patient-centered approaches that consider comorbidities, functional status, and patient preferences are increasingly emphasized in decision-making.

**Future Directions**

Ongoing research is focused on refining patient selection criteria for various interventions, developing more effective and safer thrombolytic agents, and leveraging artificial intelligence for earlier detection and risk stratification. Long-term studies are needed to assess the durability of novel techniques and their impact on quality of life and functional outcomes.

**Limitations**

Despite these advances, challenges remain. Delayed presentation, limited access to specialized centers, and variability in expertise can impact outcomes. Moreover, the risk of reperfusion injury and systemic complications continues to be a concern, underscoring the need for vigilant perioperative management.

4. Conclusion

The management of acute limb ischemia has evolved rapidly, with endovascular and hybrid techniques now complementing traditional surgery. Continued innovation, multidisciplinary collaboration, and patient-centered care are essential to further improve outcomes and reduce the burden of this life- and limb-threatening condition.

Consent (where ever applicable)

Written informed consent was obtained from all individual participants included in the study. For any case reports or identifiable data, consent for publication was obtained from the patients or their legal guardians.

Ethical approval (where ever applicable)

This study did not involve human participants or animals and was based on a review of existing literature; therefore, ethical approval was not required. All cited studies were conducted in accordance with relevant ethical standards.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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