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REVIEW ARTICLE

Clinical Aspects of Acute Mesenteric Ischaemia

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Abstract

Acute mesenteric ischaemia (AMI) is a serious disease with mortality between 50 and 80 %. Oxidative stress plays a major role in the pathophysiology of AMI. AMI should be considered for any acute abdominal pain that requires analgesia with morphine and for which no other obvious aetiology is found. CT is the main diagnostic procedure to confirm the diagnosis of AMI. There is no specific diagnostic biomarker for AMI that can be used in routine practice. AMI is an urgent diagnostic and therapeutic situation. Treatment of AMI includes a protocol combining digestive rest, curative anticoagulant, antiplatelet, antibiotic therapy, arterial revascularisation to salvage viable bowel and resection of necrotic digestive segments. The strategy of revascularisation depends on the mechanism of arterial occlusion, the morphological appearance of the lesions and the indications for exploratory laparotomy. Endovascular and open surgical techniques can be combined and complemented. Open surgical revascularisation is indicated in case of failure or impossibility of endovascular revascularisation and in case of need for laparotomy. Early diagnosis and timely surgical intervention are the cornerstones of modern treatment to reduce the high mortality of AMI. The emergence of endovascular approaches and modern imaging techniques is developing and providing new treatment options. A multidisciplinary approach based on early diagnosis and treatment is necessary.

Key words: Mesenteric ishaemia, acute; Oxidative stress; Mesenteric vascular occlusion; Diagnostic imaging; CT; Treatment.

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Introduction

Acute mesenteric ischaemia (AMI) represents a pathophysiological state characterised by an inadequacy in splanchnic blood flow, resulting in an insufficient supply to fulfil the metabolic needs of the intestine.[1] The aetiology of AMI encompasses both, arterial and venous origins, contributing to the intricate nature of this vascular disorder. In this article, focus is only on the detailed aspects of AMI caused by artery-related factors. Through an in-depth exploration of its arterial aetiology, aim is to provide comprehensive insights into the pathogenesis, clinical manifestations, diagnostic modalities and management strategies associated with this critical medical condition. According to a retrospective study dating back to 1993, AMI is reported to account for approximately one hospitalisation in 1000 in emergency departments across Europe and the United States. People older than 50 are more likely to develop intestinal ischaemia.[2] Despite this historical perspective, the diagnostic challenges associated with AMI persist, contributing to the likelihood that its true fre-

quency remains substantially underestimated. The comparison of two European studies shows a difference in the incidence of AMI estimated by the usual diagnostic methods (0.63 per 100,000 people per year) and that evaluated using a series of autopsies (12.9 per 100,000 people per year).[3,4]

The mortality of AMI is particularly high, estimated between 50 and 80 %, partly due to the diagnostic difficulty leading to a delay in treatment.[5] In a retrospective study published in 2015 in which 780 cases of AMI treated in intensive care were studied, the mortality rate was 58 %.[6] This was probably even underestimated because the study included left-sided ischaemic colitis, not rare complications of vascular surgery for abdominal aortic aneurysms and whose prognosis is less severe than in small bowel ischaemia.

The advent of expert centres (Intestinal Stroke Centre (ISC), *Structure d urgences vasculaires Intestinales* (SURVI)) in the management of AMI offers hope for improving the prognosis of this pathology.[7,8]

Mechanisms of acute mesenteric ischaemia

AMI can be of occlusive origin, with arterial involvement (85 to 95 %) largely predominating over venous involvement (5 to 15 %) or non-occlusive. AMI linked to an arterial occlusion is most often related to an embolism (40 to 50 %), which should lead to a search for cardiac arrhythmia due to atrial fibrillation, an intracardiac thrombus or an atherosclerotic plaque of the thoracic aorta. Thrombotic occlusion occurring in pre-existing atheromatous stenosis is the second most common mechanism (20 to 35 %). Dissections and vasculitis represent less than 5 % of cases. The incidence of non-occlusive AMI is very poorly evaluated because their diagnosis is difficult. The studies were carried out mainly in selected populations of patients post-operatively for cardiac surgeries or abdominal aortic aneurysms and showed an incidence of 3 to 20 %.[9-11] The pathophysiology of non-occlusive AMI is often linked to a state of shock with low flow associated with diffuse mesenteric vasoconstriction in response to hypovolaemia, reduced cardiac output and/or vasopressor amines necessary for resuscitation.

Pathophysiology of acute mesenteric ischaemia

Splanchnic circulation represents approximately 25 % of resting cardiac output.[12] The physiology of splanchnic flow regulation is complex, involving intrinsic (metabolic and myogenic) and extrinsic (autonomic nervous system and hormonal) regulation systems.[12] The interruption or significant reduction in intestinal blood flow leads to AMI from the mucous layer to the serosa according to a complex multi-step pathophysiological process, which can lead to irreversible transmural necrosis or intestinal infarction, to a multiple organ dysfunction syndrome (MODS) and death in the absence of early and appropriate treatment. Reperfusion exacerbates tissue damage to a greater extent than ischaemia alone.[1,13,14]

Oxidative stress during acute mesenteric ischaemia

In recent years, numerous studies have highlighted the significant role of oxidative stress in the pathogenesis of AMI. During reperfusion, the reintroduction of oxygen leads to an abundance of reactive oxygen species (ROS) within damaged cells and tissues. These ROS can indiscriminately target various intracellular biomolecules including membranes, organelles and DNA fragments, contributing to the progression of tissue damage. This process, oxidative stress, disrupts the dynamic balance (homeostasis) of epithelial cells through signal transmission, which is followed by the release of large amounts of inflammatory mediators and the induction of apoptosis and worsening of damage during and after reperfusion.[15] Mitochondrial DNA participates in oxidative phosphorylation of the cells and maintains normal cell function. After mitochondrial DNA damage, the production of ROS increases and this DNA is released into the cytoplasm and proinflammatory and proapoptotic factors are activated.[16] ROS mainly come from the gastrointestinal tract, pathogens can produce inflammatory factors by activating epithelial cells, polymorphonuclear cells and macrophages.[17] ROS in small and moderate quantities are useful for physiological processes, but in large excess, they can lead to oxidative tissue damage.[18] These include compounds such as superoxide anion (O_2-), hydroxyl radical (OH-) and hydrogen peroxide (H_2O_2). Beside this, nitrogen oxide (NO), nitrogen dioxide (NO_2), dinitrogen trioxide (N_2O_3) and peroxynitrite ($ONOO^-$)

are collectively named reactive nitrogen species, which are closely related to ROS and are often listed together. The common feature of these radicals is that they contain unpaired electrons and that they are highly reactive toward intracellular proteins, lipids and even DNA.[19] Under physiological conditions, ROS are neutralised by endogenous antioxidative enzymes and are not harmful to the body.[20] The mitochondrial respiratory chain regulates the production of ROS. Increased ROS generation cause the mPTP (mitochondrial permeability transition pore) to open and release apoptotic factors into the cytoplasm (Figure 1).[21] Enzymes that generate ROS *in vivo* conditions, also include lipooxygenases, glucose oxidases, nitric oxide synthetases and cyclooxygenase activation.[22] AMI can induce hypoxia, triggering the irreversible conversion of xanthine dehydrogenase (XD) to xanthine oxidase (XO). This conversion process generates ROS, contributing to tissue damage (Figure 1).[23] After the reperfusion starts and oxygen supply is renewed (oxygen wave), the electrons from XO are transferred to molecular oxygen creating significant amounts of oxygen free radicals such as O_2-, OH-, H_2O_2.[24] Intestinal ischaemia-reperfusion injury can reduce the height of intestinal villi, increasing cellular infiltration and worsening the peeling of intestinal mucosa observed histologically. In addition, proinflammatory cytokines (TNF, IL-1, IL-6) are released into the serum and lead to systemic disturbances such as systemic inflammatory response syndrome (SIRS) and MODS.[25] The endogenous antioxidants can somewhat protect cells and tissue from ROS attacks. Enzymatic antioxidants: superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPX), glutathione reductase (GSR) and heme oxygenase (HO) and nonenzymatic antioxidants such as glutathione (GSH), thioredoxin (TRX), melatonin play important role in oxidative stress homeostasis.[26]

Development of MODS during AMI

Several hypotheses have been proposed to explain the occurrence of MODS in cases of acute intestinal distress.[27, 28] The changes in the lining of the digestive system and the lymphoid tissue linked with it, known as gut-associated lymphoid tissue (GALT), along with their interaction with the normal bacteria in the intestines appear to be significant factors in causing MODS.[28, 29] The breakdown of tight junctions in the gut lining al-

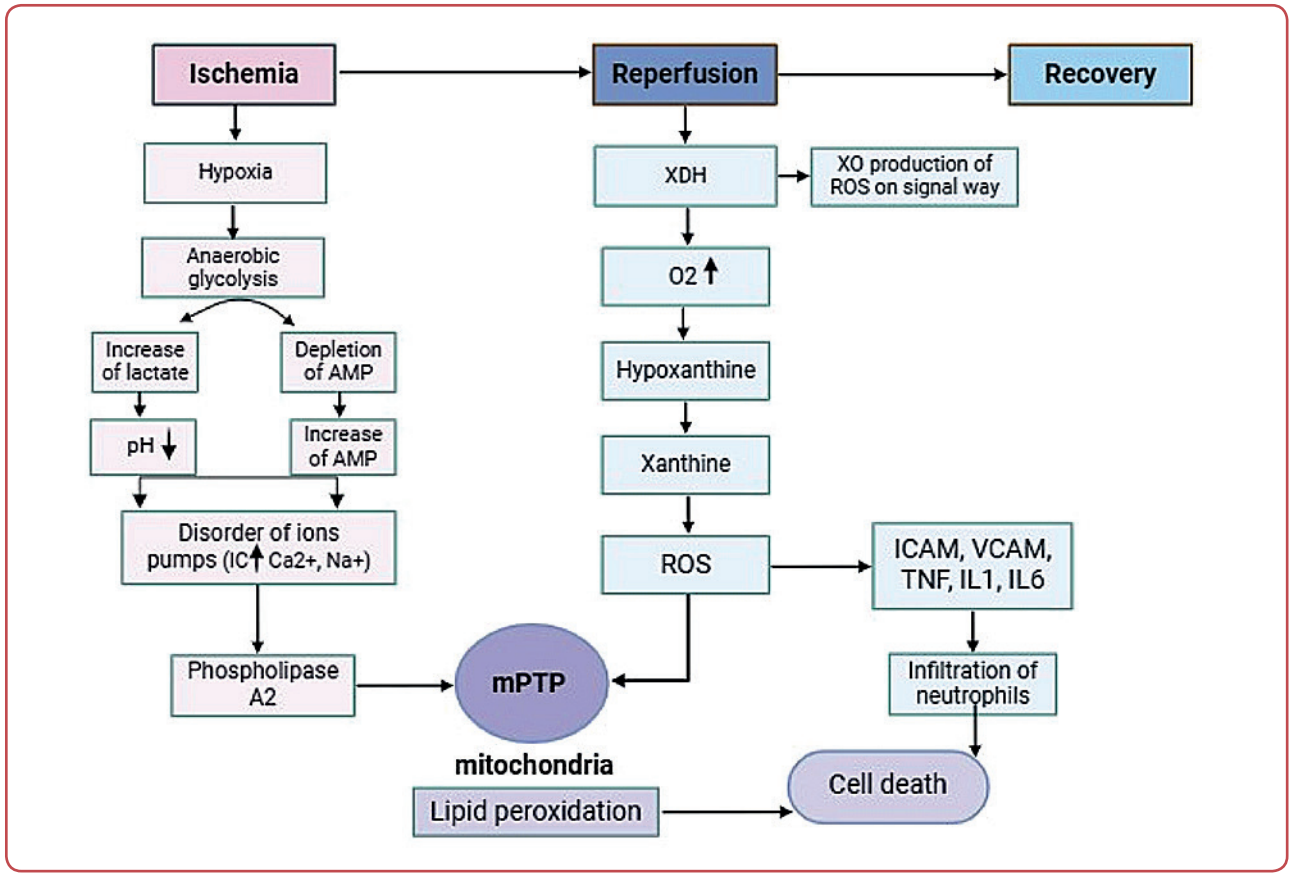

Figure 1: Patophysiologic mechanisms involved in acute mesenteric ischaemia (AMI)

lows harmful substances like bacteria, toxins and inflammatory molecules to pass into the body. Additionally, during acute intestinal distress, about half of the immune cells in the gut wall decrease due to a process called apoptosis. This weakens the body's ability to fight off pathogens from the gut, making it easier for them to enter the bloodstream and cause further problems.[30] Microbial overgrowth, mainly anaerobic, from commensal flora at the site of injured intestine due to paralytic ileus, contributes to the risk of bacterial translocation.[31, 32]

To understand the possible role of AMI in the occurrence of systemic complications such as acute respiratory distress syndrome, liver and kidney lesions, the systemic passage of pathogens from the intestinal lumen was studied in the mesenteric lymph nodes, lymphatic circulation and blood portal venous. In six clinical studies involving 2,125 patients undergoing laparotomy, primarily for cancer surgery rather than AMI, it was found that bacterial translocation into the mesenteric lymph nodes occurred in 5 to 21 % of cases. This phenomenon was linked to a higher likelihood of postoperative infectious complications.[8, 33-37] In one study that involved 20 patients with severe abdominal trauma, among whom 30 % developed MODS, an analysis of 212 blood samples obtained from the portal vein for 5 days during laparotomy revealed a singular positive blood culture for *Staphylococcus aureus*.[38] Furthermore, no endotoxin was detected. The hypothesis of systemic passage through the lymph has been evaluated by preclinical experimental studies. In particular, ligation of the mesenteric lymphatic channel in a mouse model of AMI prevented the occurrence of MODS.[39]

The role of reperfusion syndrome after ischaemia in the systemic pathogenesis of AMI should be noted.[30] Reperfusion injury is greater than ischaemia itself, from the harmful effects of ROS created during reperfusion.[30] Although the role of AMI in the occurrence of a significant and deleterious systemic inflammatory response of the "sepsis-like" type must still be clarified, it is currently recommended to administer empiric antibiotic therapy in AMI.[40, 41] In a prospective observational study, Nuzzo et al showed that empiric, enteral antibiotic therapy (metronidazole 500 mg x 3/day combined with gentamicin 40 mg x 2/day) was independently associated with a reduction in the risk of intestinal necrosis.[42]

Diagnosis of acute mesenteric ischaemia

Clinical diagnostic criteria

Contrary to popular belief, most patients with AMI consult the emergency room at an early stage that is potentially reversible, but this condition is still insufficiently recognised. The majority of patients are initially present without a known cardiovascular disease history, without signs of acute abdomen, without organ failure and without elevation of plasma lactate.[43-45] On the other hand, acute abdominal pain is constant, apart from the particular case of intensive care patients receiving sedation.[1, 46] Abdominal pain is typically sudden, intense and resistant to non-opioid analgesics, continuous, peri-umbilical or diffuse, in contrast with abdominal palpation. It may be associated with vomiting (48 %), diarrhoea (31 %), digestive bleeding (18 %) which, being inconsistent and/or too late, has no validated diagnostic value.[43] Only one of these features of acute abdominal pain warrants the diagnostic suspicion of AMI and the performance of an urgent CT angiogram, including patients with a vascular history.[1, 47]

Radiological diagnostic criteria

The cornerstone of radiological diagnosis is the CT scan, which must be considered as a first-line examination.[48, 49] The scan should be performed as quickly as possible after the onset of symptoms and the radiologist should be informed of the diagnostic suspicion. The protocol should include acquiring images both before and after contrast injection at the arterial and venous portal stages. This allows for excellent visualisation of the vessels and facilitates a thorough analysis of the digestive tract. Additionally, the intrinsic contrast provided by intestinal fluid enhances the evaluation of the intestinal wall after contrast injection.[50] Therefore, it is not advisable to administer positive oral contrast to the patient. Due to the importance of early diagnosis, the injection must be performed for any suspicion of AMI, even in cases of degraded renal function, the risk of ignoring an AMI outweighs the risk of renal toxicity.[50, 51]

1. CT semiology

CT scan plays a dual diagnostic and prognostic role in patients with AMI. It allows the demon-

stration of vascular insufficiency and ischaemic intestinal lesions and eliminates other differential diagnoses.[51]

a) Vascular insufficiency

Intraluminal defects or mesenteric vessel occlusions demonstrate high diagnostic specificity (94-100 %), but their reported sensitivity is relatively low (12-15 %). These vascular anomalies are encountered in more than 75 % of patients.[52]

Occlusive forms. In occlusive forms of AMI, the scanner allows visualisation of the site of vascular obstruction, appearing as a filling defect of the vascular lumen. Demonstration of the occlusion is easier when it is proximal and reaches the large vessels. However, a distal vascular occlusion may be the only abnormality and should be looked for. Emboli usually originate from the heart or aorta. In most patients, blood flow is preserved in the proximal branches of the superior mesenteric artery (SMA) and the jejunal arteries. Acute embolic occlusion typically appears as a sharp interruption of the vessel. Smaller emboli may be located distally or only affect small branches. Associated infarctions of other organs (spleen, kidney, liver, lower limb) suggest an embolic mechanism.[53] Arterial thrombosis occurs mainly in the context of atherosclerotic disease and results from rupture of atherosclerotic plaque. Calcified or non-calcified plaques are frequently visible at the origin of the occluded vessel. SMA thrombosis is generally more proximal than emboli, visible in the first few centimetres of the artery. In most instances, a dissecting AMI is an extension of an aortic dissection. On CT, the dissection manifests as a linear intraluminal filling defect, representing the flap that separates the true and false lumens. Dissection may also arise in the context of large or medium vessel vasculitis. In such cases, CT imaging reveals a thickening of the vascular wall, possibly accompanied by perivascular fatty infiltration.

Non-occlusive forms. In non-occlusive mesenteric ischaemia (NOMI), the basic mechanisms are decreased flow and vasoconstriction. Therefore, a CT scan may show narrowed calibre veins, flattened *inferior vena cava*, diffuse irregularities or spasms of arterial branches and poor visualisation of intestinal arches and mural vessels.[54]

b) Ischaemic intestinal distress (PPP)

CT signs of intestinal distress are intestinal wall thickness, density and strengthening of the intestinal wall, fat infiltration and dilatation of affected loops-handle calibre.

Intestinal wall thickness. Intestinal wall thickening is a very common sign of intestinal ischaemia, usually due to early, reversible mural oedema or delayed, irreversible haemorrhage.[55] This sign has high sensitivity (85-88 %) but much lower specificity (61-72 %).[56] Thickening is much more pronounced in venous insufficiency. In cases of arterial obstruction, the intestinal wall usually has a thin appearance. This thinning is secondary to the loss of blood volume of the intramucosal arterial capillaries. It may be difficult to differentiate between a thinned wall and an absent wall enhancement. This sign has a high specificity (88 %) but a low sensitivity (40 %) for the diagnosis of AMI.[57]

Density and strengthening of the intestinal wall. Spontaneous increase in intestinal wall density has been well described in ischaemia associated with small bowel obstruction and also exists in patients suffering from AMI.[58] This hyperdensity is thought to result from submucosal or transmural haemorrhage. Evaluation of bowel wall enhancement plays a very important role in the diagnosis of AMI. Diminished or absent intestinal enhancement is a major sign. This feature has high specificity (88-100 %) and sensitivity ranging from 18 to 60 %.[59-62] The relatively low sensitivity is explained by the numerous anastomotic connections between the vessels that provide blood supply to the intestine. The definition of this sign is purely qualitative and it is best appreciated by comparing the affected segments to normal adjacent loops. Paradoxical hyper-enhancement of the intestinal wall can also be observed in AMI. In patients with hypovolemic shock, the small intestine appears dilated and typically shows increased and prolonged enhancement of the intestinal wall, thought to result from splanchnic vasoconstriction and slow perfusion, as this is usually observed in patients with NOMI.[63] A stratified enhancement, called a "target" appearance, can be observed. It is explained by the enhancement of the mucosa and the exter-

nal serosa surrounding a central oedematous layer of low density. The sign is observed in cases of arterial occlusion with reperfusion, but also in NOMI or venous ischaemia.[64]

Handle calibre. Dilatation of affected loops has a sensitivity of 39 to 67 % and a specificity of 29 % to 81 % in patients with AMI.[57, 59-62, 65] Dilatation is caused by reflex interruption of intestinal peristalsis or by irreversible transmural ischaemia causing exudation of fluid into the intestinal lumen. Dilatation was more frequently reported in patients with arterial occlusion than in those with venous occlusion or NOMI. One of the difficulties is not to confuse dilatation of the intestinal wall with ileus or mechanical obstruction.[66]

Fat infiltration. Mesenteric fat infiltration is one of the most sensitive signs of AMI (reported sensitivity up to 96 %). Therefore, it attracts attention and helps identify abnormal intestinal segments. However, its specificity is much lower and varies from 28 % to 68 %.[57, 59-62, 65, 67]

2. Signs of irreversible intestinal necrosis

In addition to making the diagnosis of AMI, radiologists must know how to differentiate ischaemia and intestinal necrosis, because the latter indicates a late form of AMI and leads to different management and prognosis. The radiologist must therefore estimate the probability of the presence of necrosis based on several signs. Intraperitoneal gas is the only pathognomonic sign of intestinal perforation and therefore of transmural necrosis.[54] Ideally, intestinal necrosis should be diagnosed and resected before this stage of perforation peritonitis. *Pneumatosis intestinalis* is also a sign suggestive of necrosis, but it is important to note that it can be seen in non-necrotic segments as well. Duron et al found that 47 % of AMI patients with parietal pneumatosis still had viable bowel, with only partial mural ischaemia without transmural necrosis.[68] Patients with gas in the splanchnic veins are more likely to have transmural necrosis than those with *pneumatosis intestinalis* alone.[69]

In AMI of arterial origin, intestinal dilatation higher than 25 mm and reduction or absence of enhancement of the digestive wall are more common in cases of intestinal necrosis. In a recent prospective study, only intestinal dilatation was retained as an independent factor of irreversible transmural necrosis, emphasising the importance of this sign which would reflect the interruption of intestinal peristalsis by damage to the deep muscular layers of the digestive wall. Thus, in the case of dilatation, the rate of surgical resection is significantly higher.[43]

Relevance of biomarkers

Improving the prognosis and treatment of AMI requires the identification of 1) sensitive and specific diagnostic biomarkers for the early and reversible stage of the condition and 2) new therapeutic avenues likely to limit reperfusion injury.[70] Today's conventional analytical approaches do not fulfil either of these objectives.[46] The complex histological structure of the intestinal wall, the metabolic modulation brought by dietary and bacterial environmental factors, the shared expression of proteins by the liver and the intestine and their hepatic metabolism through the portal blood are all reasons explaining the difficulties in identifying a molecular biomarker of diagnostic or therapeutic interest.[46, 71-73]

Certain blood laboratory abnormalities (hyperleukocytosis, metabolic acidosis, elevation of CRP, LDH, AST, CPK, alkaline phosphatase, phosphate, amylase) are inconsistently found during AMI, with low diagnostic performance.[61, 63] Pancreatic proteins, neurotensin, calcitonin, D-dimer and certain inflammatory mediators (IL-2, IL-6, TNF) are not sufficiently specific for intestinal epithelial damage. Gastrointestinal polypeptides (somatostatin, VIP, substance P), which are relatively specific, are rapidly eliminated by hepatic metabolism and are not accessible to peripheral blood testing.[74] The increase in hexosaminidase and L-lactate is too delayed.[43, 74] None of the markers with the best intestinal specificity today (intestinal fatty acid binding protein (IFABP), D-lactate, alpha-glutathione S transferase, ischaemia-modified albumin (IMA) and citrulline) has clinical application in the diagnosis of early AMI. [46, 71, 73, 75]

The positive or negative predictive value of L-lactate is not sufficient to make it a biomarker that can be used in the diagnosis of AMI. In non-occlusive AMI, the elevation of L-lactate may be linked solely to low circulatory flow. In occlusive AMI, Nuzzo et al have just shown that 49 % of patients presenting to the emergency room for an AMI do not have hyperlactataemia.[43]

Diagnosis of acute mesenteric ischaemia

Multimodal and multidisciplinary care

The AMI is a complex multistep process that begins with local reversible ischaemic attack of the intestinal mucosa, which may progress to irreversible transmural necrosis. It can be further complicated by MODS in its late form. Corcos et al formed the SURVI centre, providing emergency care for AMI whose focus is on preserving intestinal vitality through a multi-modal and multidisciplinary approach.

Results of their pilot study indicated that 2-year survival was 89 %, with a bowel resection rate of 39 % and long-term parenteral nutrition of 17 %. They also showed that so-called late forms of AMI have a much worse prognosis than early forms.[7]

Protocol for the treatment of acute mesenteric ischaemia

Protocol for the treatment of AMI aims to prevent possible organ failure and to initiate the early specific treatments related to the pathophysiology of AMI. Haemodynamic stabilisation is achieved by volume expansion with crystalloids and if necessary, with the administration of vasopressor amines. As the splanchnic circulation is particularly sensitive to vasoconstriction, it is crucial to navigate the resuscitation using precise cardiovascular monitoring. This approach helps prevent the administration of excessive doses of vasopressor amines in cases when blood volume is not optimised, as well as reduces the risk of exacerbating abdominal compartment

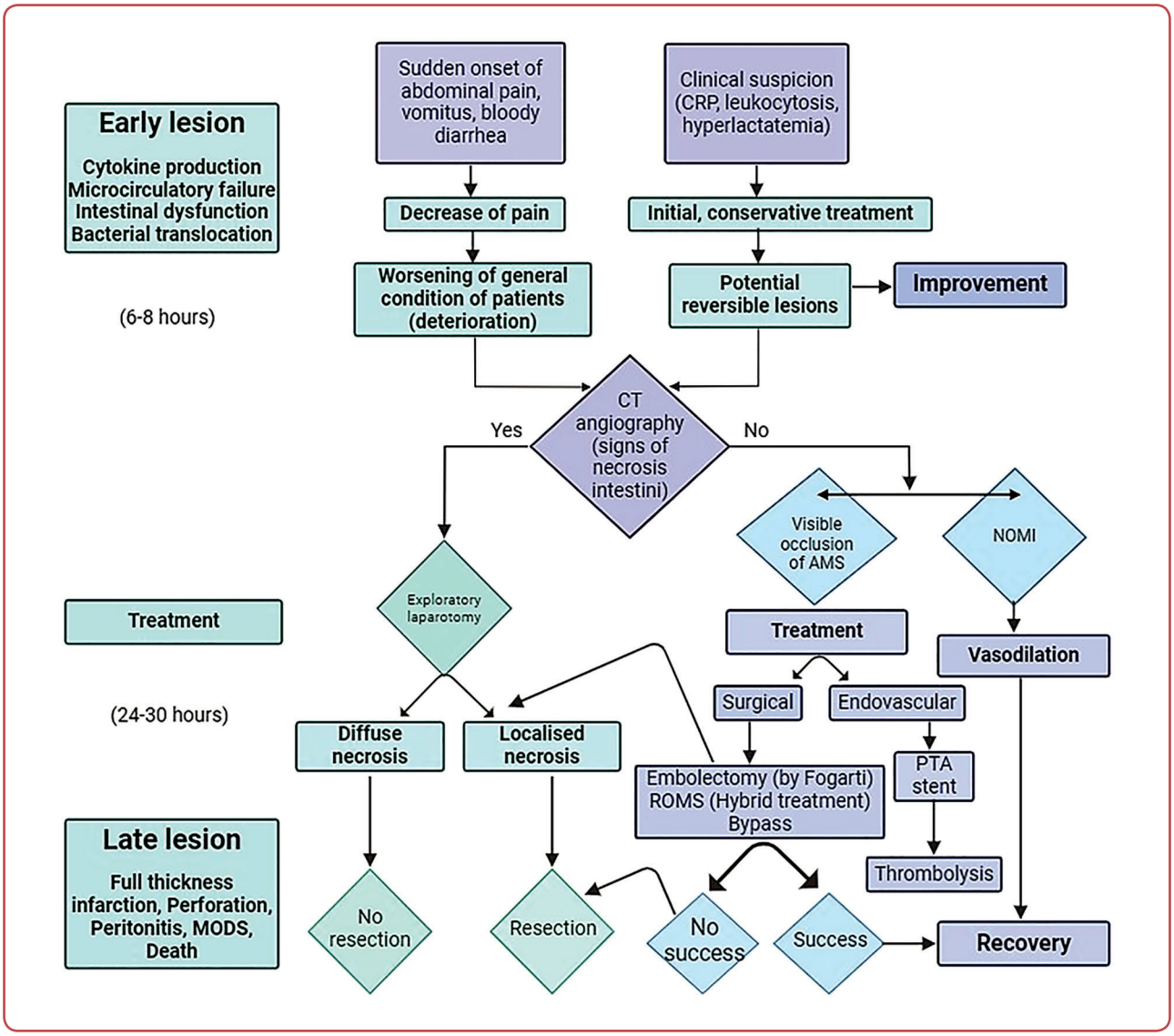

Figure 2: Algorithm for the treatment of acute mesenteric ischaemia (AMI)

MODS: multiple organ dysfunction syndrome; PTA: percutaneous transluminal angioplasty; AMS: superior mesenteric artery; NOMI: non-occlusive mesenteric ischaemia; ROMS: retrograde open mesenteric stent;

syndrome caused by unnecessary volume expansion.

Fasting and placing a nasogastric suction tube helps patients to relieve the reflex ileus. Before surgical treatment of occlusive AMI, it is necessary to quickly introduce a curative anticoagulant. For this purpose, the molecule of choice is unfractionated heparin (intravenously, 100 IJ/kg). The recommendation for antibiotic therapy is based on studies that have shown positive outcomes with selective digestive decontamination in intensive care, addressing potential infections from translocation or perforation of necrotic bowel tissue.[76]

The treatment protocol should combine broad-spectrum systemic intravenous antibiotic therapy (cefotaxime + metronidazole or piperacillin-tazobactam or cefepime + metronidazole) combined with antibiotic therapy administered enterally. The optimal method to administer the antibiotic therapy by the enteral route, particularly in patients with paralytic ileus or after gastrointestinal resection with stoma formation, still needs to be evaluated, especially in terms of duration of treatment.[76]

Indications for exploratory laparotomy

Exploratory laparotomy is necessary in several complicated conditions such as shock, suspected intestinal necrosis, peritonitis due to necrotic intestinal perforation or bacterial translocation and the necessity for open revascularisation (Figure 2). The predictive score for irreversible intestinal necrosis was established in order to more precisely identify the patients at high risk of irreversible necrosis, which requires urgent surgical evaluation.[43] This simple score includes three independent predictive factors, available after diagnosis of AMI: (1) presence of organ failure, (2) elevation of serum lactate > 2 mmol/L and (3) bowel dilatation > 25 mm on scan. Results from this study suggest that in the absence of these three factors, laparotomy can be avoided if percutaneous endovascular revascularisation is feasible.[43] With the slightest doubt, laparotomy should be widely used in other cases. Therefore, despite the null value in the positive diagnosis of AMI, L-lactate appears to have an important prognostic value, identifying the necrotic stage of AMI that requires laparotomy. As this study mainly included patients with occlusive AMI, these results cannot be generalised to non-occlusive AMI followed by systemic hypoperfusion condition of intensive care patients.[43]

Principles of digestive resection

In ideal clinical practice, revascularisation precedes and guides bowel resection, as this approach enhances the precision of defining the bowel resection margins. Revascularisation could significantly limit the extent of bowel resection. Bowel resection is predominantly conducted within peripheral healthcare centres lacking vascular surgery team while awaiting secondary transfer and in cases of pan-intestinal necrosis leading to short bowel as well as in cases of bowel perforation. The extent of digestive tract resection must be discussed collaboratively before proceeding with surgery (damage control surgery - DCS).[77] The determination of extent depends on the patient's factor: age, comorbidities and ability to consider life under total parenteral nutrition. In order to avoid dependence on total parenteral nutrition, it is recommended to maintain a minimum residual length of 100 cm of jejunum required for terminal jejunostomy, 65 cm of jejunum for jejunocolic anastomosis and 35 cm of jejunum for jejunoileal anastomosis, preserving ileocecal region.[6, 77] A postoperative surgical „second look" is not a standard procedure in every centre, but may be conducted in the presence of any suspicious remaining area or signs of secondary degradation.[78] Endoscopic control can be performed through stomas in the upstream and downstream segments of the intestine. Two practices that should be discouraged are resection - anastomosis and leaving segments of the small intestine closed in the abdomen while waiting for a „second look."

Revascularisation strategies

Mesentery revascularisation techniques depend upon the aetiology of arterial occlusion - whether atherothrombosis or embolism, along with the morphological appearance of arterial lesions and the indication for laparotomy in case of suspected bowel necrosis. The target artery that should be revascularised is the SMA. Most studies regarding this issue are single-centre and retrospective. A retrospective comparison of endovascular and open surgical revascularisation is often biased and may lack significance because these techniques are not applied to the same patients. The current problem appears to be more related to mesenteric revascularisation in AMI, which is still insufficient. This was shown in US study involving 23,744 patients with AMI, among whom only 3 % benefited from revascularisation.[79] However, approximately 70 % of patients with acute SMA obstruction require revascular-

isation to survive, while the remaining 30 % can be saved by bowel resection alone.[78, 79]

Whenever possible, endovascular revascularisation techniques are preferred, as they offer significant benefits in terms of postoperative morbidity and mortality, length of hospitalisation and nutritional recovery. Two publications from the Swedvasc registry report historical results of SMA revascularisation for AMI for the periods between 1987 and 1998 as well as between 1999 and 2006.[80, 81] Swedvasc is a vascular registry established in 1987, which collects information about more than 90 % of vascular surgical procedures performed in Sweden. Overall, surgical revascularisation quadrupled from 1999 to 2006, while the number of endovascular revascularisations increased sixfold. Although total mortality caused by this condition decreased, the reduction was observed only in patients treated with an endovascular strategy. With a similar length of bowel resection in both revascularisation techniques, the endovascular strategy stood out as an independent survival factor, as revealed by the multivariate analysis. However, the main reason for the success of the endovascular strategy was the availability of surgical revascularisation as an option in case of failure. While the data from the Swedvasc register for the period 2009-2015 are not currently available, it appears that since 2009, a significant proportion of the procedures for the AMI may have been endovascular.[81] Similar observations emerge from an analysis of the National Inpatient Sample (NIS) database in the United States. The NIS is a high-quality database that contains information for 20 % of hospitalisation episodes from nearly 1,000 US hospitals. Among 679 patients treated for AMI between 2005 and 2009, 514 (76 %) underwent open, surgical revascularisation, while 165 (24 %) patients were treated with an endovascular procedure.[78, 80] The proportion of patients undergoing endovascular intervention increased from 12 % in 2005 to 30 % in 2009. Mortality was 39 % after surgery and only 25 % after endovascular procedures. Among survivors, the proportion of patients requiring total parenteral nutrition was significantly higher after surgery than after an endovascular strategy.[78, 80]

In their early stages, AMIs of embolic origin are most often available for endovascular revascularisation through techniques such as thromboaspiration or fibrinolysis *in situ*. The technique of choice in their later stages is open, surgical embolectomy of SMA. The technique involves approaching the SMA at the root of the mesentery and dissecting the truncal SMA. Longitudinal arteriotomy is conducted to allow embolectomy with different Fogarty probes of the proximal SMA, different collateral arteries and distal dividing branches. The artery is then closed by suturing a patch (graft), whether biological or prosthetic, to prevent stenosis. An additional injection of urokinase can be applied *in situ* by direct puncture of the SMA, without increasing the risk of bleeding.[81] In atherothrombotic origin AMI, when open surgical revascularisation is chosen, two applicable techniques are retrograde open mesenteric stent (ROMS) and bypass (Figure 2).

In recent years, ROMS has become the hybrid surgical technique of choice in atherothrombotic AMI requiring exploratory laparotomy. It combines open surgical techniques with endovascular techniques. ROMS is performed by laparotomy, with an approach to the SMA similar to that used for embolectomy. Direct retrograde puncture of the SMA enables retrograde catheterisation of the SMA towards the aorta, as close as possible to the lesion. This technique has several advantages as it allows exploration of the small intestine by laparotomy. Compared to bypass, it enables faster vascular repair with comparable patency rates, while avoiding aortic clamping as well as coverage problems and infection. The most commonly used stents are covered steel balloon-mounted stents. This approach allows the combination of thrombectomy or endarterectomy procedures, as SMA atheromatous occlusions may be associated with thrombosis *in situ* or multiple distal occlusive lesions. In case of catheterisation failure, bypass surgery is always possible.[80, 81]

Mesenteric bypasses are considered as the last choice of revascularisation techniques for SMA. Even with the decreasing frequency of their use in AMI due to the advent of ROMS and endovascular techniques, bypasses continue to be indicated. They are recommended in cases of SMA stent thrombosis, ROMS failure, bypass thrombosis and for long and complex occlusions whose morphology is not suitable for endovascular treatment. Many centres prefer retrograde ilio-mesenteric bypasses as they do not require aortic clamping. The most commonly used graft is a ring-shaped Gore-Tex prosthesis. Bypasses should be isolated from alimentary loops to minimise the risk of prosthesis infection and secondary alimentary fistula.[81]

A special case of acute non-occlusive mesenteric ischaemia

Treatment of non-occlusive AMI primarily focuses on addressing the underlying cause of the shock state responsible for the low mesenteric flow. To suppress vasospasm, an option is the treatment of intra-arterial vasodilation of the SMA using substances such as papaverine or ilomedin, facilitated by the placement of an *in situ* catheter.[82, 83]

Conclusion

Predictive factors of mortality in AMI include old age, hyperlactataemia, metabolic acidosis, hypoxaemia, pneumatosis of the alimentary wall, MODS and sepsis. An active approach to diagnosis and treatment of AMI is crucial for reducing the time of recurrence and improving the prognosis, which, despite efforts, remains associated with high mortality rate. In summary, the morbidity and mortality rates remain high in cases of AMI. Over the last two decades, subtle improvements in survival have been achieved, probably due to the more liberal utilisation of second-look laparotomy, even in the older patient population. Embolic aetiology, signs of intestinal infarction at initial presentation and the presence of systemic atherosclerosis are predictors of poor outcome. The proportion of endovascular revascularisations has increased in the last decade and holds promise for further improvements facilitated by potential technical advances, including a broader range of low-profile and quick-change devices, as well as embolisation protection devices. Careful patient selection, procedural planning, meticulous technique and liberal use of the hybrid technique with retrograde access according to guidelines of World Society of Emergency Surgery are expected to additionally improve the outcome of endovascular treatment of AMI. Enhancement in overall outcome will largely depend on prompt diagnosis and appropriate therapy, whether through open or endovascular approaches, along with early and repeated bowel assessment.

Ethics

This study was a secondary analysis based on the currently existing data bases including *PubMed* and did not directly involve with human participants or experimental animals. The ethics approval was not required for this paper.

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Conflicts of interest

The authors declare that there is no conflict of interest.

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Data access

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

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