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Historical and modern intraoperative methods for determining the viability of the anastomosed ends of the colon

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Abstract

Determination of the viability of the anastomosed ends of the intestine is the most important stage in operations on the gastrointestinal tract, since their insufficient blood supply leads to formidable complications in the form of necrosis of the intestinal wall, failure of the anastomotic sutures and peritonitis. Visual methods for determining viability by peristalsis, pulsation of marginal vessels, color of the serous cover are very subjective and depend both on the experience of the surgeon and on the conditions in which operations are performed. The development of colorectal surgery is continuously associated with the study and development of methods for intraoperative determination of the viability of the anastomosed ends of the intestine. This review is devoted to various instrumental methods for determining the level of vascularization of the colon walls. The review presents data from both experimental and clinical studies, which reflect the advantages and disadvantages of these methods, allowing us to conclude that they can be used in practice. Among the most well-known methods for assessing the microcirculation of the intestinal wall during surgery, from experimental to applied, most authors single out laser Doppler fluorometry as the most modern and informative method. However, there is no consensus on its feasibility and effectiveness. Other methods for assessing microcirculation are inappropriate due to the complexity of their implementation or inefficiency. Despite this circumstance, among all the methods, perfusion fluorometry and laser fluorescein angiography compare favorably, especially the latter, since it allows to more accurately determine the state of the intestine and is rather undemanding in execution. A less accurate, but more accessible method is Doppler ultrasound, since it does not require large financial resources.

Keywords: colorectal cancer, laser fluorescein angiography, perfusion fluorometry, anastomotic suture failure, pulse oximetry.

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Introduction

Determining the viability of the anastomosed intestinal ends is the most important stage in gastrointestinal surgeries because their inadequate blood supply leads to serious complications such as intestinal wall necrosis, anastomosis suture failure, and peritonitis [1–6]. This is true in older patients with decreased vascular elasticity [5].

Intestinal viability is usually determined by visual signs (Korte's method), such as the presence of peristalsis, pulsation of marginal intestinal vessels, color of serosal covering, and absence of noticeable signs of necrosis [1, 7]. However, these methods are subjective, and their evaluation depends largely on the experience of the surgeon and the conditions during surgery. For example, the dark color of the intestine may be caused by temporary venous insufficiency, and nonpulsation of the marginal vessels of the mesentery may be caused by low arterial pressure or vascular spasms, whereas intestinal peristalsis may persist even in severely ischemic intestine [8, 9]. The insufficient blood supply in the ischemic part of the intestine may be compensated by the increased collateral blood flow; however, this does not exclude the development of ischemia in the anastomosis zone and failure of its sutures during the first 5 days [10].

This study aimed to examine the intraoperative methods of determining the level of blood supply to the intestine in colorectal surgery.

A systematic review was conducted using PubMed, Web of Science, and eLibrary.Ru databases for 1967–2022.

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Clearance of hydrogen gas

The method involves studying the removal of hydrogen gas that enters the body by breathing or intraarterially. A positively polarized electrode is inserted into the organ to be examined, which removes hydrogen from the blood flow. Considering the rate of gas uptake, the blood flow velocity is measured [11]. This method is used to assess blood flow in various organs and tissues, such as the liver or pancreas [12, 13].

However, this technique is ineffective for assessing intestinal blood supply because it has low accuracy at blood flow rates >100 mL/100 g/min or in tissues with blood flow volumes <5 mL. In addition, this technique is inconvenient to use in the operating room [13].

Polarographic oxygen pressure measurement

The mechanism of this method is based on measuring the partial pressure of molecular oxygen, which conducts a polarized current to a noble metal cathode: the lower the strength of the recorded current, the lower the concentration of molecular oxygen. However, this value indicates the oxygen content of the tissue, not the blood supply. According to Düchs and Foitzik, the degree of ischemia can be determined indirectly [14].

In 2006, Hirano et al. studied a series of 20 patients with colorectal cancer who underwent radical surgery with small intestinal anastomosis. Tissue oxygen saturation (StO_2) was measured in both the proximal and distal parts of the anastomosis site. In the case of anterior resection of the rectum, StO_2 was measured only in the proximal part. The authors observed two anastomotic complications (one failure and one stenosis) per 20 cases. In patients with and without complications, the StO_2 values were 58.0% and 71.0%, respectively. In total, 18 patients had StO_2 values >66%, and none of them had anastomotic complications. By contrast, two patients had StO_2 values <60%, and both had anastomotic complications [15].

In colorectal surgery, the StO_2 at the anastomosis site can be safely and reliably measured using near-infrared reflectance spectroscopy (NIRS). Low StO_2 levels on both sides of the anastomosis site may indicate an increased risk of anastomotic complications. According to Düchs and Foitzik, further studies are needed to determine the threshold level of StO_2 that can prevent serious complications [15].

In the study by Sheridan et al., which included 50 patients who underwent colon resection, tissue oxygen tension (PtO_2) values <20 mmHg in the anastomosis site led to its failure (at this level of PtO_2, failure occurred, and the authors cited this level as the threshold) [16].

Conversely, in the study by Jacobi et al., no decrease in submucosal PtO_2 was observed in patients with anastomotic failure following esophageal resection. However, the PtO_2 increased in six patients with anastomotic suture failure [17].

In an experimental study in rats, Boersema et al. investigated the efficacy of hyperbaric oxygenation in reducing PtO_2. Hyperbaric oxygenation improved anastomotic healing in the presence of reduced PtO_2 and improved postoperative colorectal anastomotic function in rats [18]. These conflicting data have raised doubts about the role of impaired tissue oxygenation in anastomotic healing. Currently, this technique is not widely used.

Vital microscopy

This method is considered highly reliable for microcirculation studies because it allows the visualization and assessment of changes at the capillary level. Microscopy of the serous layer of the intestine determines the effective ratio of blood cells within the channel and intrathecally, which is reliable and can be considered the “gold standard” for assessing intestinal viability.

A rat model of intestinal obstruction was used for the experimental intraoperative assessment of intestinal viability. By using images obtained by CCD microscopy[1], the ratio of the maximum blood cell transit velocity in the experimental segment to that in the reference segment and the ratio of the effective area of the vascular channel to the total area of the vascular channel in the experimental segment to that in the reference segment were calculated.

Researchers found that the group of animals that underwent microscopy and subsequent blood flow assessment in the subserosal sheath were significantly less likely to experience anastomotic suture failure than the group that did not. Real-time microscopic assessment of the extent of vascular injury can significantly reduce the rates of anastomotic suture failure. However, no experimental data on the use of this method in humans are available [19].

Ultrasound Doppler examination

Many studies have reported the use of this technique to visually assess the pulsation of marginal vessels of the intestinal mesenteric artery, either in addition to or separately. According to the results of studies published in 2019, Doppler sonographic measurement of the hemodynamics of the anastomosed intestine showed potential value in predicting anastomotic failure [20].

[1] CCD, charge-coupled device

In total, 163 eligible patients were included in the final analysis (male, n = 96; female, n = 67, with a mean age of 60 (range, 25–83) years. Fifteen (9.2%) patients experienced anastomotic suture failure, of which three patients underwent a second surgery. The median time of occurrence of anastomotic suture failure was the postoperative day 8 (range, 4–20 days). No delayed anastomotic suture failure occurred in this study [20].

To obtain sufficient length of the proximal colon for tension-free anastomosis, all patients underwent ligation of the sigmoid or left colonic artery. To assess the blood supply to the proximal part of the anastomosed colon, Doppler hemodynamic measurements were recorded before and after vessel ligation at the same site near the anastomosed colon. Measurements were started after the fixation of the clamp in the colon and then repeated after the ligation of the sigmoid or the left colonic artery. Each measurement was repeated until a stable waveform was recorded. The advantages of this study method include its simplicity, high availability, speed, and low cost. In addition, this method does not pose any risk to the patient [20].

According to Rodin et al. [1], the ultrasound signal from larger vessels may distort the signal from smaller vessels, and close contact with the examined tissue is required, which may reduce local microcirculation and misinterpret the obtained data. The authors believe that Doppler ultrasound is associated with a high incidence of false-positive and false-negative results; currently, this method is significantly inferior to laser Doppler and perfusion fluorimetry [1, 21–26].

Radioisotope examination

This method is realized through the intravenous and intraarterial injection of radioisotope preparations into the submucosa of the ischemic intestinal segments or anastomosis zone. The method includes the registration of the elimination of intraarterially administered ^{85}Kr (krypton isotope) from the colon segment, where γ and β radiations of the indicator are registered simultaneously by a scintillation detector and a Geiger–Muller tube, respectively. Total blood flow was determined by recording γ-radioactivity using a modified Zirler formula. The total colonic blood flow was 18 ± 2 mL/min in 100 g of colonic tissue (n = 21) [27].

A similar method was used to assess blood flow at an overlapping colonic anastomosis. Two radioactive microspheres, namely, ^{141}Ce (cerium) and ^{46}Sc (styrene), were used to measure colonic blood flow in dogs before and after surgical resection with stapled anastomosis. Anastomotic healing is theoretically related to the blood flow to the anastomotic site. Blood flow studies were performed in three dogs by using this technique. The mean preoperative and postoperative blood flows were 0.558 and 1.04 mL/min/g, respectively. These results indicate a statistically significant ($p < 0.05$) increase in the blood flow at the anastomosis site 6 days after anastomosis compared with the blood flow at the same site before surgery [28].

Another study also compared the flow rate of iodine-125 through three types of anastomosis: stapler, standard, and Gambee anastomosis. When the results were compared, the flow rate through the stapler anastomosis was significantly higher than those through the standard and Gambee anastomoses [29].

Data from these experiments demonstrate the successful application of radioisotope examination to assess blood flow in anastomosed intestinal segments. Despite its relatively accurate indicators of microcirculatory assessment, radioisotope examination has several critical disadvantages, such as radiation exposure to the personnel and patient, the need to maintain specialized equipment and dispose of isotopes, and availability of more advanced methods; thus, this method is not currently used [30].

Pigmented vasoscopy

This method includes the injection of a dye into the root of the mesenteric artery of the examined intestine or the proposed anastomosis area. After 10–15 min, the well-blooded part of the intestine is actively stained, and the dye is less in the ischemic zone, which allows the establishment of clear boundaries of the intestinal resection [31].

Kochnev and Ageev (1967) developed a method of assessing the blood supply to any part of the gastrointestinal tract by injecting dyes into the artery of the examined intestinal area. They used 0.4% indigo carmine solution as a dye because it showed the fastest resorption after injection. In the experiments, 1.5–2.0 mL of the dye solution was injected into one of the main arteries of the small intestine. In 2–3 s after the start of the experiment, the intestinal area supplied with blood by this artery was stained with the corresponding color. The arterial pulsation after dye injection was weakened for 1–2 min and then restored.

Thus, the possibility of staining the main vessels, arteries, and their branches was confirmed. The authors suggested the possible use of the experience to assess the integrity of the anastomosis both postoperatively and intraoperatively, at the time of selecting the proposed site of intestinal resection [31].

Kochnev performed four intestinal graft transplants to confirm the good blood supply of the selected intestinal segment as a result of color staining. The intestinal graft was resected with the length from 6 to 15 cm within the stained length of the intestinal segment. The blue-stained mesenteric vessels and lymphatic pathways were contoured. Intestinal integrity after cutting out the graft was restored “end-to-end” by two-row sutures. Then, at a distance of 30–40 cm from this anastomosis site, a loop of the small intestine was crossed, and the cut graft was transplanted. No postoperative complications occurred. Autopsies on days 4, 6, and 9 of the experimental animals (the author did not specify which animals) showed good engraftment of the transplanted intestine. Pulsation of the graft vessels was pronounced [31].

The advantages of pigmented vasoscopy include high power, availability, speed, and possible repeated use because of the rapid dye resorption. Disadvantages include traumatization of the mesenteric vessels [31].

Pulse oximetry

In this method, two different wavelengths of light (940 and 660 nm) passed from a single source through the tissue, allowing a portion of the electromagnetic radiation to pass through and registering the remaining signal on the sensor on the back of the tissue. In this case, free hemoglobin absorbs more light at 660 nm, and oxyhemoglobin absorbs more light at 940 nm. A sensor opposite the radiation source measures the intensity of the light that passes through the tissue, and the ratio of the different wavelengths can be used to estimate StO_2.

Salusjärvi et al. demonstrated that the StO_2 value can be used to assess possible anastomotic failure. The mean colonic StO_2 values were 91.1% and 93.0% in patients who developed and did not develop anastomotic suture failure, respectively. In the logistic regression analysis, the risk of anastomotic suture failure was 4.2 times higher for StO_2 values of 90% [32].

Other studies have used pulse oximetry to measure oxygen saturation of the superior mesenteric artery by reversible occlusion. This method can assess the degree of ischemia intraoperatively and effectively predict the risk of necrosis of a strangulated intestinal loop or anastomotic suture failure. StO_2 values >76% may indicate reversible changes such as mucosal necrosis, transmural stasis, or mucosal hemorrhage, whereas StO_2 values <64% may indicate persistent transmural necrosis [33, 34].

However, Delfrate et al. suggested using pulse oximetry as an additional assessment technique because it does not allow for the assessment of blood flow but only reflects the degree of tissue oxygen saturation [35].

In addition, this method was associated with false-positive and false-negative results [36].

Measurement of hydrogen index

This method involves noninvasive measurement of the hydrogen (pH) level within the myocytes of the intestinal wall (pHi). When the blood supply within the mucosa is reduced, the pH shifts to an acidic environment. To perform this procedure, a silicone balloon catheter is inserted into the intestinal lumen and filled with isotonic sodium chloride solution. This allows carbon dioxide to diffuse freely. After some time, the partial pressure of carbon dioxide (pCO_2) in the solution inside the balloon catheter is equal to the pCO_2 of the intestinal mucosa. Then, the catheter is removed, its readings are taken and compared with the value of arterial bicarbonate, and the intramuscular pHi is calculated using the Henderson–Hasselbach equation. pHi is measured immediately after completion of the anastomosis and at intervals of 6–12 h up to 5 days after surgery [37].

In the study by Kamiya et al., the mean pHi value in patients immediately after surgery was 7.32 ± 0.11 [37]. The mean value gradually increased and remained stable between 7.32 and 7.41. On the contrary, pHi decreased to <7.10 in three patients with vascular obstruction. The pHi decreased to <7.10 in two patients with vascular obstruction by thrombus within 30 h after surgery and in 11 patients after 54 h. In these three patients, the pHi continued to decrease to 6.72 ± 0.16 within 24 h after reaching <7.10. Based on early pHi findings, the critical pHi value is 7.1 [37, 38].

Milan et al. [38] analyzed 90 patients who underwent rectal resection for cancer and found that a decrease in pHi to <7.24 in the first 24 h after surgery increased the risk of anastomotic failure by a factor of 22. However, as an accurate technique, this method is more suitable for monitoring the degree of intestinal ischemia in the postoperative period to predict or early diagnose anastomotic suture failure [38].

Measurement of intestinal contractility

This method involves the quantitative measurement of intestinal wall contractions using a special device. The device consists of a sensitive probe that is attached to the serosal surface of the intestine and detects peristaltic waves, which are recorded on the control unit as a myogram. Intestinal activity is measured at 2-cm intervals. Quantitative counts are made in millivolts on the electromyogram. Low values correspond to the ischemic parts of the intestine, whereas complete absence corresponds to necrosis [39].

Experimentally, Orland et al. induced ischemia in the intestinal wall using one of the two methods: a chronic model in which blood supply to 40 cm of the ileum was stopped and viability was assessed after 24 h and an acute model in which the main superior mesenteric artery was occluded for 0.5 h and then released. In 20 dogs with induced prolonged intestinal obstruction, 3 died of necrosis, whereas in the acute obstruction group, none of the 12 dogs died. In the acute model, electromyography values increased steadily after reperfusion and stabilized at 15 min. The mean values between 15 and 30 min after release were significantly higher than the values 5 and 10 min after and before release, indicating the effect of reperfusion on the electromyogram [39].

Brolin et al. used this technique as the only parameter for viability assessment and simultaneously with fluorometry and Doppler ultrasonography [40]. Measurement of intestinal wall contractions is not the method of choice because it requires a considerable amount of time for effective assessment of viability given that after reperfusion of the ischemic part of the intestine, electromyography data reach normal values only after 15 min [39].

Thermography

In this method, infrared radiation is used to scan temperature differences between adjacent structures: the lower the intensity of the radiation, the lower the temperature of the examined tissue area, which corresponds to poor blood supply. Nishikawa et al. showed that thermography is quite informative for assessing the viability of the gastrointestinal tract during surgery [41].

According to Rosengarten (1969) [42], the most regular parameter characterizing the viability of an intestinal loop is the viability index, which is the ratio of temperature shifts between the loop under study (for a certain time) and the intestine with confirmed viability.

The experiments utilized a TEMP-60 electrothermometer with a division measurement of 0.2°. During laparotomy, the surface temperature of a typical intestinal loop decreased to a distinct level, ultimately reaching a specific temperature plateau. This plateau's precise level depends on the temperature of the surrounding environment. Any subsequent temperature decreases are negligible. A necrotic intestinal loop can be compared to a physical object that undergoes heat exchange without physiological processes that regulate the inflow and outflow of heat. Therefore, in cases of euteration, the temperature of the intestine with reduced blood flow rapidly drops and approaches that of the surrounding environment.

To obtain accurate results, the temperature of the everted intestinal loops must be measured. Direct measurement of the temperature in the abdominal cavity may yield false readings because the intestinal loops will acquire the temperature of the nearby internal organs. The viability index was subjected to testing through animal experiments and a suboperative study involving 480 patients with conditions whose pathogenesis is based on an angiologic component [42].

However, this technique was not widely used because temperature is an indirect blood flow indicator and its fluctuations can significantly rely on the temperature of adjacent structures [43].

Fluorescence research methods

Fluorescence techniques were first used in 1976 to evaluate retinal vessels and are widely used in ophthalmology [44]. In this technique, the main technical procedures are laser fluorescence angiography (FA) and perfusion fluorimetry. Both methods revolve around injecting a fluorescent drug intravenously and observing its distribution in the intestine, which is then illuminated by an ultraviolet lamp. In perfusion fluorimetry, viable intestinal regions illuminated with sodium fluorescein appear bright green, whereas necrotic or ischemic regions do not fluoresce under reflected ultraviolet light. This technique can be used for laparotomy with a Wood's lamp or laparoscopy with ultraviolet illumination [45, 46].

In fluorescence studies of patients with colorectal cancer, indocyanine green dye can identify all metastatic nodes. Consequently, reliable information regarding the lymphogenic dissemination of these tumors can be acquired [47–49].

In 2015, the American College of Surgeons conducted an open clinical trial at 11 centers to assess the feasibility and usefulness of FA in intraoperative perfusion assessment during left-sided colectomy and anterior rectal resection. The study enrolled 147 participants, of which 13 were deemed suitable for the analysis. The most prevalent reasons for surgery were diverticulitis (44%), rectal cancer (25%), and colorectal cancer (21%).

The mean anastomosis location was 10 ± 4 cm from the anus. The mobilization of the splenic flexure was performed in 81% of the patients, and high ligation of the inferior mesenteric artery was performed in 61.9% of the patients.

FA altered the surgical plan for 11 (8%) patients, with most changes occurring during proximal end resection (7%). The complication rate was 17%, and the anastomotic suture failure rate was 1.4% (n = 2). Among the 11 patients who had their surgical plan changed based on the intraoperative per-

Table 1. Frequency of colonic anastomotic suture failures

Authors	Number of patients		Frequency of anastomotic suture failures		p
	FA+	FA –	FA+	FA –	
Boni L. et al., 2017 [55]	42	38	0	2 (5%)	<0,05
Kin C. et al., 2015 [56]	173	173	13	11	0,67
Kim J.C. et al., 2015 [57]	123	313	1 (0,8%)	17 (5,4%)	0,031
Kim J.C. et al., 2017 [58]	310	347	2 (0,6%)	18 (5,2%)	<0,001
Kudszus S. et al., 2010 [54]	201	201	7 (3,5 %)	15 (7,5%)	0,01
Mizrahi I. et al., 2018 [59]	30	30	0	2 (6,7%)	0,492
Ashraf S.Q. et al., 2013 [60]	254	31	9 (3,5%)	6 (19,4)	0,003
Jafari M.D. et al., 2015 [26]	173		2 (1, 4%)		—

Note: FA, fluorescence angiography.

fusion assessment with FA, no anastomotic suture failure was observed [50].

A multicenter study that examined 2272 gastrointestinal confocal laser microscopy procedures analyzed the safety of intravenous fluorescein contrast agents. No serious adverse events were recorded. Mild adverse events, including nausea/vomiting, transient arterial hypotension without shock, injection site erythema, diffuse rash, and mild epigastric pain, were observed in 1.4% of the patients. However, the study was limited by its active monitoring of only events occurring immediately after the procedure. The most common dose of contrast agent administered was 2.5–5 mL of 10% sodium fluorescein [51].

One of the issues with perfusion fluorimetry is the high viscosity of the preparation, which causes sodium fluorescein to adhere to tissues and renders repeated assays ineffective [32].

In most cases, the dye is excreted from the body through the urine within 12–24 h. However, small amounts of the dye remained for 2–3 days in one patient with acute renal failure without any apparent adverse effects [52].

A more precise method of examining fluorescence is through laser FA that involves intravenous injection of indocyanine green and local laser illumination. Processed digital video recordings provide a clearer image of the blood supply and intestinal viability. Compared with perfusion fluorimetry, the advantage of laser FA is that it allows repeated administrations of sodium indocyanate into the venous bed, as the dye is promptly absorbed by the liver and excreted with bile [53].

Kudzsus et al. intraoperatively evaluated all anastomotic margins by laser FA. The control group was composed of patients who underwent colorectal resection between 1998 and 2003 without laser FA. Owing to suture failure at the anastomotic site, 33 surgical revisions were necessary: 7 (3.5%) in the laser FA group and 15 (7.5%) in the control group. The subgroup analysis revealed a revision rate of 3.1% (laser FA group) and 7.7% (control group) for planned resections, with a 60% reduction in the risk of revision. In patients aged >70 years, the laser FA group had a revision rate of 4.3% compared with the control group that had 11.9%, resulting in a decrease of 64%. After manual anastomosis, the laser FA group had a revision rate of 1.2%, whereas the control group had 8.5%, leading to a decrease of 84% in the risk of failure. The laser FA group also had a significantly shortened hospital stay. The fluorescent preparation had a high level of safety, allowing for repeated uses during surgery without harming the patient [54].

Boni et al. (2019) found that incorporating intraoperative laser FA led to a modification of the resection level, effectively preventing any suture failures at the anastomosis site (p. 55).

In addition, Kin et al. reported that laser FA application required a change in the resection line of the colon mesentery in 25% of the cases because of the visualization of the lymphatic duct by indocyanine green [56].

Cost-effectiveness is a vital factor in comparing intraoperative blood flow control techniques. When compared with other techniques such as Dopplerometry, perfusion fluometry, and selective angiography, laser FA demonstrated an economic benefit (an average of $67 per study). This analysis highlights the financial advantage of using laser FA for blood flow control during surgery. However, laser FA has limitations because of the surgeon’s ability to only identify fluorescent blood flow within their immediate visibility. As a result, crucial areas of interest may be concealed by vessel branches, clips, aneurysms, and other factors [56].

Table 1 displays studies that have investigated the incidence of anastomotic suture failure with and without the use of laser FA. The authors provide data, utilizing a critical level of significance of $p = 0.05$ for testing statistical hypotheses.

Conclusions

Several techniques can be employed for evaluating intestinal blood flow intraoperatively, which can help lessen the risk of anastomotic suture failure during colorectal resection. However, not all methods are practical because of disadvantages or imperfect technology. Among the methods utilized to assess intestinal wall microcirculation during surgery, ranging from experimental to applied, most experts highlight the importance of laser Doppler fluorometry as the most advanced and informative technique. However, no agreement has been established on the practicality and efficacy of this approach. The use of other techniques for evaluating microcirculation is impractical because of their complex execution or lack of effectiveness.

Among all available options, perfusion fluorimetry and laser FA are the most effective methods, with laser FA as the preferred choice because of its superior accuracy in determining the condition of the intestine and ease of performance. Although less precise, Doppler ultrasound is a more economical approach because it does not require significant material resources. During the postoperative period, pH-metry can effectively monitor the anastomosis state and potentially predict anastomotic suture failure.

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