Early abdominal closure with mesh reduces multiple organ failure after ruptured abdominal aortic aneurysm repair: Guidelines from a 10-year case-control study

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Objective: **The objectives of this study were the comparison of patients who needed mesh closure of the abdomen with patients who underwent standard abdominal closure after ruptured abdominal aortic aneurysm repair and the determination of the impact of timing of mesh closure on multiple organ failure (MOF) and mortality.**
Methods: **We performed a case-control study of patients who needed mesh-based abdominal closure (n = 45) as compared with patients who underwent primary closure (n = 90) after ruptured abdominal aortic aneurysm repair.**
Results: **Before surgery, the patients who needed mesh abdominal closure had more blood loss (8 g versus 12 g of hemoglobin; $P < .05$), had prolonged hypotension (18 minutes versus 3 minutes; $P < .01$), and more frequently needed cardiopulmonary resuscitation (31% versus 2%; $P < .01$) than did the patients who underwent primary closure. During surgery, the patients who needed mesh closure also had more severe acidosis (base deficit, 14 versus 7; $P < .01$), had profound hypothermia (32°C versus 35°C; $P < .01$), and needed more fluid resuscitation (4.0 L/h versus 2.7 L/h; $P < .01$). With this adverse clinical profile, the patients who needed mesh closure had a higher mortality rate than did the patients who underwent primary closure (56% versus 9%; $P < .01$). However, the patients who underwent mesh closure at the initial operation (n = 35) had lower MOF scores ($P < .05$), a lower mortality rate (51% versus 70%), and were less likely to die from MOF (11% versus 70%; $P < .05$) than the patients who underwent mesh closure after a second operation in the postoperative period for abdominal compartment syndrome (n = 10).**
Conclusion: **This study reports the largest experience of mesh-based abdominal closure after ruptured abdominal aortic aneurysm repair and defines clinical predictors for patients who need to undergo this technique. Recognition of these predictors and initial use of mesh closure minimize abdominal compartment syndrome and reduce the rate of mortality as the result of MOF. (J Vasc Surg 2002;35:246-53.)**

The mortality rate after ruptured abdominal aortic aneurysm (AAA) has remained nearly constant, with multiple organ failure (MOF) representing a leading cause of death in those patients who survive operative repair.[1-9] Intra-abdominal hypertension is an important factor in the development of MOF and begins when hematoma from aortic rupture and edema from fluid resuscitation reduce abdominal domain (Fig 1, *A*). A compromised abdominal space may or may not be obvious at the end of the operation but instead manifest in the early postoperative period as elevated intra-abdominal pressure. A reduced abdominal compartment and elevated intra-abdominal pressure compress the vena cava, liver, bowel, and kidneys and worsen end-organ perfusion (Fig 1, *B*).[10-19]

Temporary abdominal closure with impermeable mesh or Silastic sheeting first was introduced in the pediatric and trauma literature. Mesh-based closure expands the abdominal domain and reduces intra-abdominal pressure (Fig 1, *C*).[20-23] Despite concerns of graft infection and wound complications, this surgical adjunct has been reported in small series after ruptured aneurysm repair.[24-26] In most instances, the mesh is sewn to the skin or fascia at completion of the operation to expand the abdominal compartment. The mesh may be tightened or changed as edema and hematoma resolve. In the postoperative period, the mesh is removed and primary fascial closure is accomplished or a piece of absorbable mesh used to restore abdominal domain.

Despite the acceptance and potential benefit of this technique, the clinical profile of the patients who need mesh-based abdominal closure after ruptured AAA repair has not been defined. In addition, no clinical predictors exist that indicate which patients may benefit from this

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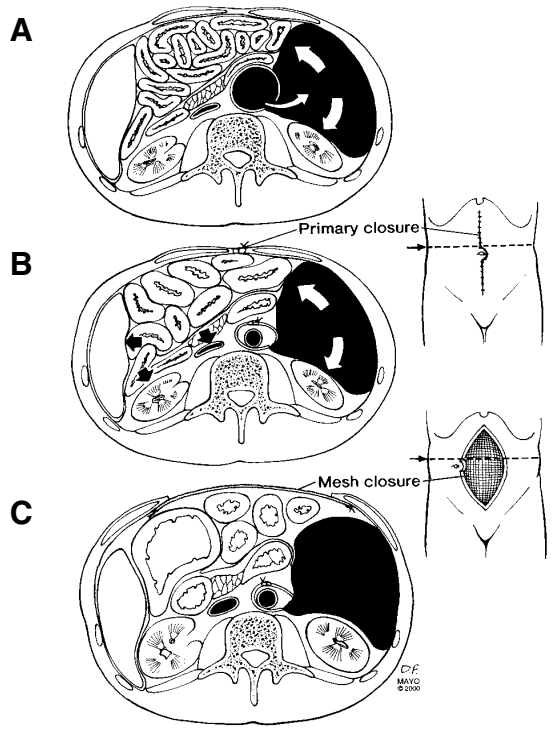

Fig 1. A, Ruptured abdominal aortic aneurysm with associated retroperitoneal hematoma and reduction of abdominal domain. **B,** Standard primary abdominal closure of compromised abdominal space after ruptured aneurysm repair with compression of abdominal structures. **C,** Closure of abdomen with impermeable mesh or Silastic sheeting expands abdominal domain and reduces pressure on abdominal structures.

technique. Finally, the impact of this technique on MOF and mortality has not been determined. The objectives of this study were the comparison of patients who needed mesh closure of the abdomen with patients who underwent standard abdominal closure after ruptured AAA repair and the determination of the impact of timing of mesh closure on MOF and mortality.

METHODS

The records of 223 patients who underwent ruptured AAA repair between January 1, 1991, and December 31, 2000, at the Mayo Clinic were reviewed.

Study group. Fifty-three patients from this group (24%) underwent mesh-based abdominal closure after ruptured AAA repair, and the remainder underwent standard primary abdominal closure (Fig 2). Three patients with mesh abdominal closure who died in the operating room and five patients who died within 6 postoperative hours were excluded from the study because their deaths were believed not to relate to closure technique. The remaining 45 patients comprised the study group (group 1). Within this group, 35 patients underwent early mesh abdominal closure at the conclusion of the initial operation and 10

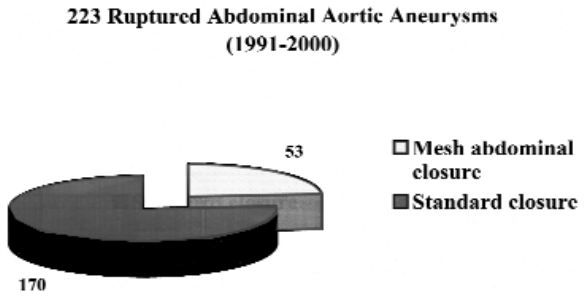

Fig 2. Charts of 223 patients with ruptured abdominal aortic aneurysms were reviewed. Fifty-three cases of mesh abdominal closure after operation were identified as compared with 170 cases of standard primary abdominal closure.

patients underwent late mesh closure after a second operation in the early postoperative period for intra-abdominal hypertension (decompressive laparotomy).

Control group. Two patients who underwent standard abdominal closure after ruptured AAA repair were identified as controls for each of the 45 patients in group 1. The control patients were time-matched to reduce outcome and experience bias during the study period. Specifically, one control patient underwent ruptured aneurysm repair before and one patient underwent repair after each patient for mesh closure in group 1. In a similar manner, the control patients who died in the operating room (18 patients) or within 6 postoperative hours (six patients) were excluded from the study. Two of the identified 90 control patients declined permission for use of clinical data which left 88 patients (group 2) for statistical comparisons.

Data collection and definitions. The demographic and clinical data from the two groups were collected in a retrospective chart review. The demographic data included age, gender, presence of comorbid disease, and previous abdominal operation. The preoperative clinical data included weight, body mass index (kg/cm^2), hemoglobin, units of blood transfused, duration of hypotension (systolic blood pressure, <90 mm Hg), and cardiac arrest or need for cardiopulmonary resuscitation (CPR). Cardiac arrest and need for CPR were defined as asystole or ventricular fibrillation, when available, or blood pressure measured as zero and pulselessness witnessed by trained medical staff in the field or emergency room. The intraoperative data included lowest temperature, greatest base deficit, duration of hypotension (systolic blood pressure, <90 mm Hg), operative time, number of units of blood transfused, total liters of fluid given per hour of operation, use of supraceliac clamp, type of graft, and presence of operative complications.

Volume of intraoperative fluids included liters of crystalloid and synthetic colloids and packed red blood cells (250 mL/U), fresh frozen plasma (300 mL/U), and platelets (50 mL/U or 300 mL per six pack). Salvaged blood (cell-saver) returned to the patient was not included in the intraoperative fluid calculation because of inconsis-

Table I. Organ failure scoring

Score	*0*	*1*	*2*
Pulmonary*	No dysfunction	Dysfunction	Failure
Renal	Creatinine level increase, 0.5 to 0.9 from baseline	Creatinine level increase, 1.0 to 2.0 from baseline	Creatinine level increase, >2.0 from baseline
Hepatic†	Bilirubin level, 2 to 4	Bilirubin level, >4.0	Bilirubin level, >8.0
Intestinal	Suspicion of ischemia	Endoscopic documented ischemia	Bowel resection
Cardiac‡	Minimal inotrope	Moderate inotrope	High inotrope

*Derived adult respiratory distress syndrome scoring system on the basis of chest x-ray, PaO_2/FiO_2 ratio, minute ventilation, and positive end expiratory pressure–determined lung dysfunction.
†Not attributed to biliary obstruction or resolving retroperitoneal hematoma .
‡Cardiac index of <3.0 *with* requirement of inotropic support: minimal inotrope dopamine or dobutamine, <5 μg/kg/min; moderate inotrope, 5 to 15 μg/kg/min; and high inotrope, >15 μg/kg/min or epinephrine drip.

Table II. Demographic analysis and frequency of preoperative comorbid disease

	Group 1 (n = 45)	*Group 2 (n = 88)*	P *value*
Age (years; median)	75 (range, 58 to 91)	74 (range, 49 to 90)	.34
Male	89%	90%	.88
Past abdominal surgery	27%	28%	.83
Coronary disease	20%	11%	.18
Renal insufficiency	36%	25%	.2
COPD	29%	25%	.63
Hypertension	62%	47%	.12
Liver disease	9%	1%	.06

COPD, Chronic obstructive pulmonary disease.

tencies in the recording of this volume encountered during data abstraction.

Postoperative morbidity, mortality, and survival rates. The presence of postoperative MOF in each group was analyzed at 12 and 48 hours and at 7 days after ruptured AAA repair. MOF was quantified with a modified scoring system described by Moore and Moore[27] on the basis of the function of five organ systems: pulmonary, renal, hepatic, intestinal, and cardiac (Table I).[27,28] Each system was scored from 0 to II (0, no dysfunction; I, mild dysfunction; and II, severe dysfunction), and the scores were added at specific postoperative periods.

An adult respiratory distress syndrome score on the basis of chest x-ray, PaO_2/FiO_2 ratio, minute ventilation, and positive end expiratory pressure determined degree of pulmonary dysfunction or failure. Degree of kidney and liver dysfunction was on the basis of increased serum creatinine and bilirubin levels, respectively. Heart dysfunction was on the basis of cardiac index and requirement of inotropic support. Bowel dysfunction, not included in Moore and Moore's[27] MOF score, was examined in this study because of the established significance of bowel ischemia after ruptured AAA and was graded on the basis of the extent of documented ischemia.[29-31]

In-hospital mortality, mortality from MOF, and long-term survival rates were calculated. In addition, a descriptive analysis of technical considerations related to mesh placement and abdominal wall complications was performed.

Comparisons and statistical analysis. Comparisons of demographic and clinical characteristics and postoperative MOF scores and in-hospital mortality rates between the study groups were evaluated with logistic regression. The threshold of statistical significance was set at $P < .05$. To determine the impact of timing of mesh closure, these same comparisons were made between the 35 patients who underwent early mesh closure and the 10 patients who underwent late mesh closure at a second operation.

RESULTS

There was no statistically significant difference found in age, gender, or frequency of prior abdominal surgery between the patients in group 1 who needed mesh abdominal closure and the control patients in group 2 (Table II). There was also no statistically significant difference found between the two groups with respect to the frequency of preoperative comorbid diseases.

Before surgery, the patients in group 1 had lower hemoglobin levels, had a longer duration of hypotension, and were more likely to need CPR than the patients in group 2 (Table III). There was no statistically significant difference found in patient weight or body mass index between the two groups. During surgery, the patients in group 1 needed a greater resuscitative volume per hour of operation, developed more profound hypothermia, and had a worse base deficit than group 2. Frequency of supraceliac clamp application was also more common in the patients in group 1 than in the patients in group 2 (Table III). There was no statistically significant difference found between groups in the operative time, type of graft used, or frequency of intraoperative complications.

Table III. Preoperative and intraoperative clinical profiles

	Group 1 (n = 45)	*Group 2 (n = 88)*	P *value*
Preoperative parameters*			
Hemoglobin (g)	8.5	11.6	<.01
Time SBP, <90 mm Hg (minutes)	18	3	<.01
Cardiac arrest (CPR)	31%	1%	<.01
Weight (kg)	86	80	.25
Body mass index	28	25	.06
Intraoperative parameters*			
Liters per hour of operation	4	2.7	<.01
Lowest temperature (°C)	32.5	35	<.01
Base deficit	14	7	<.01
Supraceliac clamp	78%	42%	<.01
Operative time (minutes)	190	171	.15
Tube graft placement	71%	53%	.05

*Median.
SBP, Systolic blood pressure; *CPR,* cardiopulmonary resuscitation.

Table IV. Demographic analysis and frequency of preoperative comorbid disease

	Early mesh (n = 35)	*Late mesh (n = 10)*	P *value*
Age (years; median)	74 (range, 58 to 91)	80 (range, 67 to 88)	.2
Male	91%	80%	.32
Past abdominal surgery	26%	30%	.79
Coronary disease	20%	20%	1
Renal insufficiency	37%	30%	.68
COPD	26%	40%	.38
Hypertension	66%	50%	.37
Liver disease	9%	10%	.89

COPD, Chronic obstructive pulmonary disease.

Morbidity, mortality, and survival rates. With this adverse clinical profile, the patients in group 1 who underwent mesh-based abdominal closure had greater mean MOF scores at 12 hours (1.4 versus 0.8; $P = .03$), 48 hours (1.9 versus 1.0; $P = .02$), and 7 days (1.9 versus 0.9; $P = .01$) than did the control patients in group 2. In-hospital mortality rate was also greater in group 1 (56%; 95% confidence interval [CI], 40 to 70) than in group 2 (9%; 95% CI, 4 to 17; $P < .01$) as was mortality rate as the result of MOF, which was 24% (95% CI, 13 to 40) versus 7% (95% CI, 3 to 14; $P < .01$). Survival rate at 5 years for patients in group 1 who needed mesh closure was 32% (95% CI, 19 to 54) versus 53% (95% CI, 40 to 72) for control patients. The in-hospital mortality rate for all ruptured AAAs in this study, including those in patients who died in the operating room and in the immediate postoperative period, was 39% (65 of 165; 95% CI, 32 to 47).

Early versus late mesh closure. There was no statistically significant difference found in the demographic characteristics or in the frequency of comorbid disease between the 35 patients who underwent early mesh closure and the 10 patients who underwent late mesh closure at a second operation for the development of intra-abdominal hypertension (decompressive laparotomy; Table IV). The patients who underwent early mesh closure also had similar preoperative and intraoperative clinical profiles as compared with the patients who underwent late mesh closure (Table V). No patients in the early mesh closure group had intra-abdominal hypertension or abdominal compartment syndrome develop. Despite similar demographic and clinical profiles, the patients in the early mesh group had lower mean MOF scores at 12 hours, 48 hours, and 7 days than did the patients in the late mesh group (Fig 3). The incidence rate of endoscopic-documented colon ischemia, an important element in the MOF score, was significantly less in the early mesh group as compared with the late mesh group (6% versus 40%; $P < .05$). In addition, the patients in the early mesh group tended to have lower mortality and death rates from MOF than did the patients in the late mesh closure group (Fig 4).

Technical considerations. In 84% of patients who underwent initial or early mesh closure of the abdomen, there was specific mention of a physically reduced abdominal domain in the operative report. Most commonly, this condition was swollen bowel (68%) or massive retroperitoneal hematoma (50%). None of the 10 patients who underwent late mesh closure after decompressive laparotomy had specific reason for loss of abdominal domain noted in the operative report. In 69% of the mesh closure cases, impermeable Silastic mesh or sheeting was used, although expanded polytetrafluoroethylene was used 13% of the time. The remaining 18% of the patients received

Table V. Preoperative and intraoperative clinical profiles

	Early mesh (n = 35)	*Late mesh (n = 10)*	P *value*
Preoperative parameters*			
Lowest hemoglobin (g)	8	10.1	.05
Time SBP, <90 mm Hg (minutes)	20	20	.6
Cardiac arrest (CPR)	34%	20%	.4
Weight (kg)	85	90	.75
Body mass index	28	28	.68
Intraoperative parameters*			
Liters per hour of operation	4	4.4	.91
Lowest temperature (°C)	32.1	32.8	.56
Base deficit	14	13	.6
Supraceliac clamp	80%	70%	.51
Operative time (minutes)	209	169	.07
Tube graft placement	63%	100%	.01

*Median.
SBP, Systolic blood pressure; *CPR,* cardiopulmonary resuscitation.

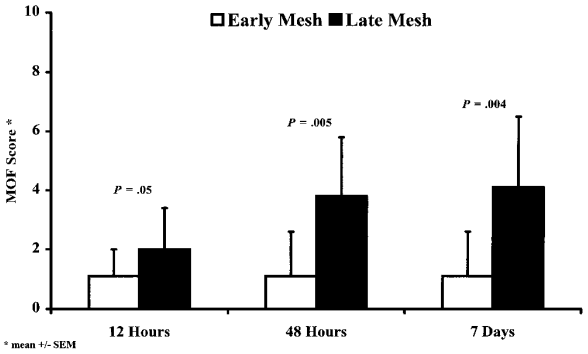

Fig 3. Multiple organ failure scores at 12 hours, 48 hours, and 7 days after ruptured abdominal aortic aneurysm repair. *MOF,* Multiple organ failure; *SEM,* standard error of the mean.

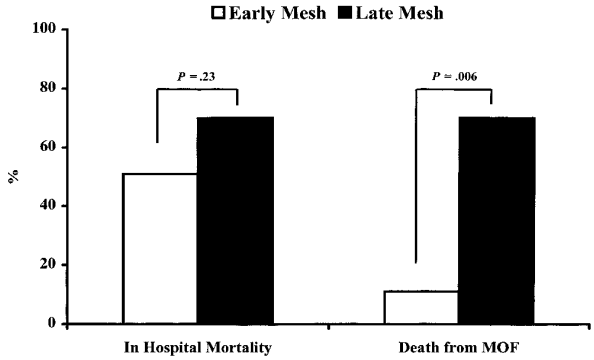

Fig 4. In-hospital mortality and death rates from multiple organ failure *(MOF)* in patients who underwent early mesh closure as compared with patients who underwent late mesh closure after decompressive laparotomy.

various types of nonabsorbable sheeting or Vicryl. Mesh materials were most commonly sewn to the fascia in 84% of the cases and to the skin in only 16% of cases. Nineteen patients (45%) in group 1 needed one return trip to the operating room for reasons related to abdominal closure, most commonly for mesh removal and final restoration of abdominal domain. Sixteen patients (38%) needed two or more returns to the operating room. The initial mesh was removed between postoperative days 2 and 7, with fascial closure accomplished in 42% (14 of 33) of the patients. An equal number of patients (42%) were unable to have fascial closure and received absorbable mesh (eg, Vicryl) at the final abdominal wall-related operation.

Wound-related complications. The most common early abdominal wall complication in patients from group 1 was dehiscence of mesh material from fascia or skin in the postoperative period (22% of cases). Chronic abdominal wall hernia occurred in 33% of the patients from group 1 and always followed the use of Vicryl mesh for final abdominal closure. One of the 15 patients with chronic abdominal wall hernia had symptoms, and all the hernias were managed conservatively with abdominal binders. Enterocutaneous fistula occurred in three patients (7%) from group 1, each after the use of Vicryl mesh. There were no documented vascular graft infections in the study group (32% 5-year survival rate).

DISCUSSION

This study reports the largest experience of mesh-based abdominal closure after ruptured AAA repair, and the results show that this technique may be used in severely compromised cases with acceptable outcome. In addition, these findings define objective clinical differences between patients who need this technique and those who need standard primary abdominal closure. Finally, this study shows that mesh closure at the initial operation reduces morbidity and mortality rates from MOF as compared with later mesh closure after a second operation for intra-abdominal hypertension.

The results of this analysis confirm specific clinical trends first observed by the Harborview group in a smaller study of this technique.[26] Specifically, the findings in both studies suggest that patients who need mesh closure after ruptured AAA repair are distinct with regards to three pre-

operative (anemia, duration of shock, and need for CPR) and three intraoperative (hypothermia, acidosis, and volume of resuscitation) parameters. Recognition of these clinical differences in two separate studies suggests that they may have a role in the prediction of which patients need this technique. Although findings in both studies show that mesh-based abdominal closure may reduce morbidity and mortality rates from MOF, the current investigation results suggest that such benefit is only present if mesh closure is used at the original operation.[22,26,32]

The higher incidence rate of colon ischemia (40%) in the late mesh group is important. It may be hypothesized that increased postoperative fluid requirements associated with colon malperfusion contributed to the development of abdominal compartment syndrome, which necessitated laparotomy and late mesh closure in some patients. In contrast, the incidence of colon ischemia in the early mesh group (6%) is low, considering the group's adverse perioperative profile. This finding suggests that early expansion of the abdominal domain with mesh may reduce the detrimental effects of increased abdominal pressure on bowel perfusion. These observations are supported by studies in which the adverse effects of prolonged intra-abdominal hypertension on organ perfusion and the development of MOF have been established.[12-19,33] The absence of aortic graft infection in this study confirms other reviews that report that the placement of temporary mesh does not predispose to graft infection.[25,26]

Limitations. The limitations of this study rest primarily in its retrospective nature. Specifically, it is not possible to prove that the technique of mesh-based abdominal closure offers benefit to such critically ill patients nor is it possible to quantify the predictive value of these clinical parameters. These propositions were not objectives of this study and would be addressed more appropriately in a prospective trial. In addition, the calculation of organ failure scores in a retrospective manner is difficult and subject to data availability. However, the same definitions and data abstraction methods were applied to both study groups. Finally, considerable selection bias was introduced into the study with the exclusion of patients who died in the operation room or in the immediate postoperative period. The exclusion of these patients resulted in an unusually low mortality rate in the control group (9%), which should be recognized as influenced by selection bias. The in-hospital mortality rate of all the ruptured aneurysms in this study was 39%.

Clinical implications. As is commonly the case with retrospective clinical reviews, the most valuable yield of this study is "not necessarily the discovery of new concepts, but the illumination and refinement of ideas and impressions already known but dimly defined."[34] In this context, this study confirms general impressions that patients who need mesh closure after ruptured aneurysm repair "are more sick" than patients who undergo primary closure. However, these results extend this clinical impression, define the adverse clinical profile for patients who need this technique, and show that its early application may reduce the rate of MOF.

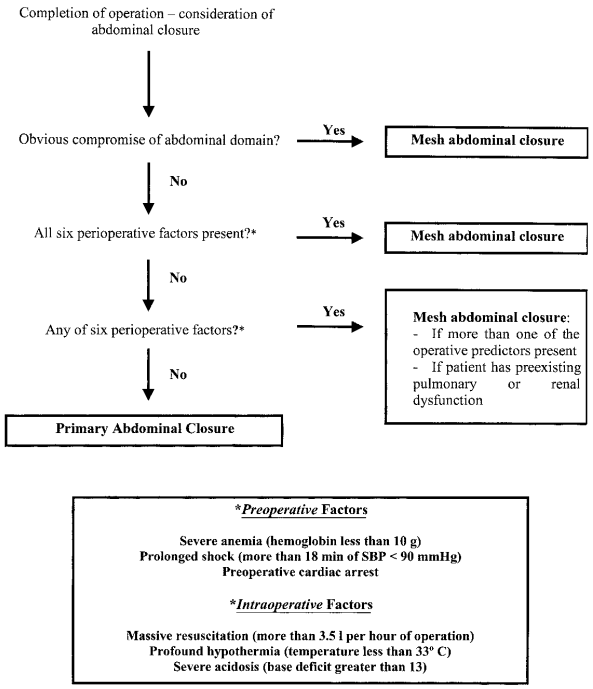

Fig 5. Algorithm for consideration of clinical factors in use of mesh-based abdominal closure after ruptured abdominal aortic aneurysm repair. *SBP,* Systolic blood pressure.

The adverse clinical profile defined in this study may guide the use of mesh-based abdominal closure after ruptured aneurysm repair (Fig 5). Patients with obvious loss of abdominal domain will need mesh closure. Another group that would need mesh closure is patients who do not have noticeable loss of abdominal domain but do have the clinical profile predictive of abdominal compartment syndrome. These patients are at high risk for the development of intra-abdominal hypertension or abdominal compartment syndrome if they undergo primary closure. Six clinical factors are associated with the development of intra-abdominal hypertension or abdominal compartment syndrome (preoperative anemia, prolonged shock, and need for CPR, intraoperative massive fluid resuscitation, severe acidosis, and profound hypothermia). If these factors are present, mesh closure should be applied, even if the abdomen can be closed primarily. Conversely, if none of the clinical factors are present, then primary abdominal closure may be performed. When some but not all of the clinical factors are present, mesh closure is favored if more than one of the operative predictors is present or if the patient has a preexisting organ dysfunction (especially renal or pulmonary).

Technical considerations. The study results suggest that impermeable mesh or Silastic sheeting sewn to fascia at the conclusion of the initial operation is preferable. The removal of this mesh 2 to 5 days after the operation with primary fascial closure was possible in nearly one half of

the patients in group 1. Early dehiscence that necessitated a return to the operating room occurred in nearly one fourth of the mesh closure cases. This complication represents a significant pitfall and may have occurred as the result of inadequate suturing of mesh to the fascia or failure to keep the patient adequately sedate during the early postoperative period.

The use of absorbable Vicryl mesh was necessary in nearly half of the patients from group 1 when the original mesh or sheeting was removed and fascial closure was not possible. Although the use of Vicryl in this situation was necessary, it was associated with chronic abdominal wall hernia in all cases and an enterocutaneous fistula in three cases (16%). No patients with abdominal wall hernia had significant symptoms, and all conditions were managed with abdominal binders that reflected the general activity level of the patients who survive this ordeal. The development of enterocutaneous fistula reflects general concerns regarding the use of Vicryl and suggests that it should only be used at the final abdominal closure operation when fascial closure cannot be accomplished.[22]

CONCLUSION

This study reports the largest experience of mesh-based abdominal closure after ruptured AAA repair and defines clinical predictors for patients who need this technique. The recognition of these predictors and the initial use of mesh closure minimizes abdominal compartment syndrome and reduces mortality as the result of MOF.

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REFERENCES

1. Noel AA, Gloviczki P, Cherry KJ Jr, Bower TC, Panneton JM, Mozes GI, et al. Ruptured abdominal aortic aneurysm: the excessive mortality of conventional repair. J Vasc Surg 2000. In press.
2. Gloviczki P, Pairolero PC, Mucha P Jr, Farnell MB, Hallett JW Jr, Ilstrup DM, et al. Ruptured abdominal aortic aneurysms: repair should not be denied. J Vasc Surg 1992;15:851-9.
3. Johansen K, Kohler TR, Nicholls SC, Zierler RE, Clowes AW, Kazmers A. Ruptured abdominal aortic aneurysm: the Harborview experience. J Vasc Surg 1991;13:240-7.
4. Johnston KW, the Canadian Society for Vascular Surgery Aneurysm Study Group. Ruptured abdominal aortic aneurysm: six-year follow-up results of a multicenter prospective study. J Vasc Surg 1994;19:888-900.
5. Panneton JM, Lassonde J, Laurendeau F. Ruptured abdominal aortic aneurysms: impact of comorbidity and postoperative complications on outcome. Ann Vasc Surg 1995;9:535-41.
6. Halpern VJ, Kline RG, D'Angelo AJ, Cohen JR. Factors that affect the survival rate of patients with ruptured abdominal aortic aneurysms. J Vasc Surg 1997;26:939-48.
7. Tilney NL, Bailey GL, Morgan AP. Sequential system failure after rupture of abdominal aortic aneurysms: an unsolved problem in postoperative care. Ann Surg 1973;178:117-22.
8. Katz DJ, Stanley JC, Zelenock GB. Operative mortality rates for intact and ruptured abdominal aneurysms in Michigan: an 11-year statewide experience. J Vasc Surg 1994;19:804-17.
9. Tromp Meesters RC, van der Graaf Y, Vos A, Eikelboom BC. Ruptured aortic aneurysm: early postoperative prediction of mortality using an organ system failure score. Br J Surg 1994;81:512-6.
10. Bradley SE, Bradley GP. Effect of increased intra-abdominal pressure on renal function. J Clin Invest 1947;26:1010-2.
11. Richardson JD, Trinkle JK. Hemodynamic and respiratory alterations with decreased intra-abdominal pressure. J Surg Res 1976;20:401-4.
12. Harmon PK, Kron IL, McLachlan HD, Freedlender AE, Nolan SP. Elevated intra-abdominal pressure and renal function. Ann Surg 1982;196:594-9.
13. Richards WO, Scovill W, Shin B, Reed W. Acute renal failure associated with increased intra-abdominal pressure. Ann Surg 1983;197:183-7.
14. Caldwell CB, Ricotta JJ. Changes in visceral blood flow with elevated intra-abdominal pressure. J Surg Res 1987;43:14-20.
15. Cullen DJ, Coyle JP, Teplik R, Long MC. Cardiovascular, pulmonary, and renal effects of massively increased intraabdominal pressure in critically ill patients. Crit Care Med 1989;17:118-21.
16. Schein M, Wittman DH, Aprahamian CC, Condon RE. The abdominal compartment syndrome: the physiological and clinical consequences of elevated intra-abdominal pressure. J Am Coll Surg 1995;180:745-53.
17. Diebel LN, Dulchavsky SA, Wilson RF. Effects of increased intra-abdominal pressure on mesenteric arterial and intestinal mucosal blood flow. J Trauma 1992;33:45-8.
18. Diebel LN, Wilson RF, Dulchavsky SA, Saxe J. Effect of increase intra-abdominal pressure on hepatic arterial, portal venous and hepatic microcirculatory blood flow. J Trauma 1992;33:279-83.
19. Obeid F, Saba A, Fath J, et al. Increases in intra-abdominal pressure affect pulmonary compliance. Arch Surg 1995;130:544-8.
20. Mayberry JC, Mullins RJ, Crass RA, Trunkey DD. Prevention of abdominal compartment syndrome by absorbable mesh prosthetic closure. Arch Surg 1997;132:957-62.
21. Torrie J, Hill AA, Streat S. Staged abdominal repair in critical illness. Anaesth Intensive Care 1996;24:368-74.
22. Smith JH, Merrill RC, Raffin TA. Reversal of postoperative anuria by decompressive celiotomy. Arch Intern Med 1985;145:553-4.
23. Kron IL, Harman PK, Nolan SP. The measurement of intraabdominal pressure as a criterion for abdominal reexploration. Ann Surg 1984;199:28-30.
24. Fietsam R Jr, Villalba M, Glover JL, Clark K. Intra-abdominal compartment syndrome as a complication of ruptured abdominal aortic aneurysm repair. Am Surg 1989;55:396-402.
25. Akers DL Jr, Fowl RJ, Kempczinski RF, Davis K, Hurst JM, Uhl S. Temporary closure of the abdominal wall by use of silicone rubber sheets after operative repair of ruptured abdominal aortic aneurysms. J Vasc Surg 1991;14:48-52.
26. Oelschlager BK, Boyle EM Jr, Johansen K, Meissner MH. Delayed abdominal closure in the management of ruptured abdominal aortic aneurysms. Am J Surg 1997;173:411-5.
27. Moore FA, Moore EE. Evolving concepts in the pathogenesis of postinjury multiple organ failure. Surg Clin North Am 1995;75:257.
28. Moore FA, Sauaia A, Moore EE, Haenel JB, Burch JM, Lezotte DC. Postinjury mulitple organ failure: a bimodal phenomenon. J Trauma 1996;40:501-12.
29. Levison AL, Halpren VJ, Kline RG, Faust GR, Cohen JR. Perioperative predictors of colonic ischemia after ruptured abdominal aortic aneurysm. J Vasc Surg 1999;29:40-7.
30. Meissner MH, Johansen KH. Colon infarction after ruptured abdominal aortic aneurysm. Arch Surg 1992;126:979-85.
31. Koike K, Moore FA, Moore EE, et al. Gut ischemia mediates lung injury by xanthine oxidase dependent neutrophil mechanisms. J Surg Res 1992;32:723.
32. Shelly MP, Robinson AA, Hesford JW, Park GR. Haemodynamic effects following surgical release of increased intra-abdominal pressure. Br J Anaesth 1987;59:800-5.
33. Peerless JR, Alexander JJ, Pinchak AC, Piotrowski JJ, Malangoni MA. Oxygen delivery is an important predictor of outcome in patients with ruptured abdominal aortic aneurysms. Ann Surg 1998;227:726-34.
34. Szilagyi DE, Smith RF, Elliott JP, Vrandecic MP. Infection in arterial reconstruction with synthetic grafts. Ann Surg 1972;176:321-33.

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DISCUSSION

Dr Frank J. Veith (Bronx, NY). As you probably know, we have been using endovascular grafts to treat ruptured abdominal aortic aneurysms. To date, we have done 22 cases with only an 8% mortality. Interestingly, three of these patients developed distinct abdominal compartment syndrome despite the fact that we were using an endovascular graft; and these three patients required an abdominal decompression in addition to their endovascular grafting.

Dr Peter R. F. Bell (Leicester, United Kingdom). We've been interested in this for a while as well. There are so many different factors that it's difficult trying to decide which patients to deal with. We've also been trying to measure the bladder pressure, which is the recommended method of looking at abdominal pressure in these patients, but couldn't find a correlation between those who have the problem and the bladder pressure. Could you comment on this, please?

Dr Todd E. Rasmussen. We were unable, in a retrospective manner, to consistently collect bladder pressures. I think this question would be most appropriately answered in a prospective study. We do know, however, that intraabdominal pressures of greater than 15 mm Hg decrease renal function and decrease end-organ perfusion.

Dr Jeffrey L. Kaufman (Springfield, Mass). This is extremely important. We've adopted the same strategy and have accumulated around 15 patients the last decade.

Among the issues that confront surgeons with this problem are serious questions pertaining to bleeding. I'd like you to tell us whether any of your patients had to return to the OR earlier than expected because of bleeding through the mesh. You can have bleeding through the drapes used to pack off the mesh at the end of the case, and you will receive calls from the ICU or recovery area that bleeding seems excessive. How do you deal with this? Do you have an algorithm that tells you this is probably just venting of retroperitoneal hematoma as opposed to some primary hemorrhage from your repair? That's one issue that comes up.

The other issue is the timing of removing the mesh. One of the serious issues we've run into is the patient who is doing well at postop day 3 or 4, who returns to surgery to snug up on the mesh or actually remove it, and who then develops abdominal compartment syndrome. In our experience, it can be hard to estimate exactly where the abdominal compartment is in terms of swelling and the physiological response that will occur. We've had a couple patients where it was never possible to remove the mesh, where we have waited until the viscera fused to the fascia, and where closure was achieved with supplemental skin grafts to the exposed bowel.

This is a really important issue. I think our survival mirrors yours, that it is better to leave the abdominal cavities open rather than create an abdominal compartment syndrome. I commend you for this work.

Dr Rasmussen. The issue of bleeding is an important one. I think there is some theoretical advantage to primary closure in providing tamponade and the cessation or reduction of postoperative bleeding.

There were about five patients in the study group who had to be returned to the operating room for bleeding. Those patients all had primary bleeding problems identified, either from the aortic anastomosis or unrecognized intraoperative injury. The mesh itself is mostly impermeable, so that there is no bleeding through the mesh into the wound. All of those returns were based on hemodynamics and decrease in hemoglobin and not bleeding "through the mesh."

Dr Lazar J. Greenfield (Ann Arbor, Mich). I'm interested in physiology that may involve more than the abdominal compartment. It would seem that ventilatory pressures might be different between these groups that you have defined, and I'm surprised that you didn't look into that variable as well.

The assumption that you're making that you've been able to accurately segregate the patients who need this help is a little confusing to me, because I think what you have done is to define a very high-risk population. I think the thesis that you're proposing remains to be proved by a more randomized study.

Dr Rasmussen. To answer the second question first, I agree that these factors can really only be proven to be predictors in a prospective study. What this study has hopefully done is to identify specific clinical factors that surgeons should be aware of during this difficult type of case.

The issue of airway pressures is important, and it was factored into our multiple organ failure score that will be outlined in the manuscript.

Dr Robert B. Patterson (Providence, RI). The trauma services have encountered this to a great extent with their multiple trauma patients. And one of the things they're championing is using sterile 3-liter IV bags, irrigation bags from the urology service, that they literally tuck in from flank to flank and then place some sterile gauze over that, put some suction drains, and then a large sterile drape. We've used this in a couple of situations. It really allows you to widely drain the area. It's very rapid in terms of a nonclosure activity. It's easy for the nursing staff to take care of because the suction drains keep the fluid out of the bed, and then you return them to the operating room several days later, change the dressings, inspect them, and at some point you can just do a definitive closure either with mesh or with primary closure. Have you had any experience with this?

Dr Rasmussen. With that specific technique, no. And all of the 45 patients in this study had the mesh or Silastic sheeting sewn either to the fascia or the skin. But I think as more experience is developed and taken from the trauma literature, that's probably a reasonable idea.

The downside of tucking closure material under the abdomen wall is that you lose the fascia. If you're not sewing to the fascia, it will retract and primary closure may be ultimately more difficult. In this salvage type of situation, one is just trying to, in some quick way, restore abdominal domain and get the patient out of the operating room. I think that the technique you describe is a reasonable alternative.

Dr Jesse A. Blumenthal (New York, NY). We've had the same experience with the trauma patients as the aneurysm patients. Have you tried just primary skin closure alone, mobilize the skin and then in 48 or 72 hours either close primarily or then use the mesh?

Dr Rasmussen. Again, all of the patients in this study had the mesh either sewn to the fascia or the skin. So, in this group, no, that technique has not been tried, but would also be another reasonable option.

Dr Clifford J. Buckley (Holland, Tex). I just wondered if you would comment on the rather high incidence of ruptured aneurysms in your series encompassing 10 years. I calculate it to be one every 2 weeks. Most ruptured aneurysms come from an area surrounding a medical facility, which is where I suppose most of these came from. That seems like an unusually high incidence of ruptured aneurysm.

Dr Rasmussen. It seems like quite a few ruptured aneurysms to me also. It's about 23 a year.

Dr Gloviczki and the Mayo Group will be publishing a paper in the coming months which looks more at the incidence of ruptured aneurysms and their overall mortality. St Mary's Hospital at Mayo captures ruptured aneurysms not only from Olmsted County, but also from a large region including southern Minnesota, northern Iowa, and southwestern Wisconsin.