

Surgical and endovascular repair for type B aortic dissections with mesenteric malperfusion syndrome: A systematic review of in-hospital mortality



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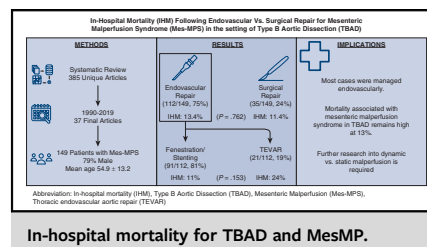
ABSTRACT

Objectives: Mesenteric malperfusion is a feared complication of aortic dissection, with high mortality. The purpose of this study was to systematically review in-hospital mortality (IHM) of endovascular and surgical management of acute and chronic Stanford type B aortic dissections (TBAD) complicated by mesenteric malperfusion (MesMP).

Methods: A systematic search of English language articles was conducted in relevant databases. Data on patient demographics, procedure details, and survival outcomes were collected. Reports were classified by type of intervention performed. Studies that failed to report patient-level outcomes based on specific intervention performed or IHM were excluded. Retrospective chart review of previously published data from a single institution was also performed to further identify cases of TBAD that were managed endovascularly. The Fisher exact test was performed to determine statistical significance.

Results: In total, 37 articles were suitable for inclusion in this systematic review, which yielded 149 patients with a median age 55.0 years (interquartile range, 46.5–65 years) and 79% being male. Overall, in-hospital mortality was 12.8% (19/149) and was similar between endovascular and open surgical interventions (13% vs 11%, $P = .99$). Among endovascular strategies, IHM was greater, although not statistically significant in the thoracic endovascular aortic repair group compared with the fenestration/stenting without thoracic endovascular aortic repair group (24% vs 11%, $P = .15$).

Conclusions: Multiple strategies exist for the management of TBAD with MesMP; however, a majority of cases were managed endovascularly. Despite advances in therapies, mortality remains high at 13%. (JTCVS Open 2022;12:37–50)



CENTRAL MESSAGE

Endovascular and surgical management of type B aortic dissection with mesenteric malperfusion (TBAD-MesMP) have comparable in-hospital mortalities, which remain high despite advances in therapies.

PERSPECTIVE

Type B aortic dissection complicated with mesenteric malperfusion may be managed with open, endovascular, and hybrid treatment strategies, all of which still have significant in-hospital mortality and necessity for bowel resection despite advances in therapy. Further research into choosing the appropriate therapy is required.

Video clip is available online.

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Type B aortic dissection (TBAD) is a life-threatening condition in which a tear develops in the intima of the aortic wall distal to the origin of the left subclavian artery. TBADs are often stratified into uncomplicated versus complicated to determine management strategy. The standard of care for uncomplicated TBAD is medical management with blood pressure and heart rate control to prevent aortic rupture and propagation of the dissection. Complicated TBAD denotes dissection accompanied by aortic rupture, refractory pain, rapid aortic expansion, uncontrollable hypertension, or malperfusion.¹ Malperfusion refers to inadequate blood

Abbreviations and Acronyms

CT	= computed tomography
IRAD	= International Registry of Acute Aortic Dissection
MesMP	= mesenteric malperfusion
SMA	= superior mesenteric artery
TBAD	= type B aortic dissection
TEVAR	= thoracic endovascular aortic repair

flow to a vascular territory and is present in approximately 20% to 30% of type B aortic dissections.^{1,2} Malperfusion syndrome is decreased flow to vascular territory resulting in tissue/end-organ necrosis and dysfunction secondary to dissection-related impairment of blood flow. In particular, mesenteric malperfusion (MesMP) has been associated with a particularly poor prognosis and a significant increase in mortality (3- to 4-fold increase).³

Diagnosis of MesMP is based on clinical, radiographic, and laboratory features, including the presence of abdominal pain (most common symptom³), bloody diarrhea, tenderness to palpation, diminished blood flow in the superior mesenteric artery (SMA) with or without SMA thrombosis on computed tomography (CT) imaging, and signs of ischemia, such as thickened bowel wall, elevated lactate, and metabolic acidosis.⁴ The signs and symptoms of MesMP can be persistent or intermittent, contributing to the diagnostic challenge, but the symptoms often correlate to the degree of obstruction.³ Obstruction can be dynamic, static, or a combination of dynamic and static.⁵ Dynamic obstruction results from prolapse of the dissection flap across or into the ostium of the branch vessel, thereby obstructing flow with a degree of obstruction varying with blood pressure. Paradoxically, in many cases visceral organ perfusion improves with reduction in systemic blood pressure.^{6,7} Dynamic obstruction can usually be resolved with restoration of the true lumen in continuity with the heart. In contrast, static obstruction results from extension of the dissection into the branch vessel with inadequate or absent reentry based on manometry. Static obstruction must be relieved by an intervention targeting the particular mechanism of true lumen compromise including stenting, thrombolysis, thromboembolectomy, and fenestration.

The presence of MesMP in type B aortic dissection classifies it as a complicated TBAD, therefore necessitating intervention following initial medical stabilization. With the advent of endovascular therapies over recent years, multiple options exist for treating complicated type B aortic dissection, including thoracic endovascular aortic repair (TEVAR), fenestration and stenting, and open surgical repair.^{2,6,8} Endovascular therapy, specifically TEVAR, has been established as superior to open surgical repair for

complicated TBAD in multiple studies and reviews.⁹⁻¹² However, the primary goal of TEVAR is to cover the primary intimal tear to restore true lumen flow, which can resolve dynamic obstruction but does not reliably relieve static obstruction, which may require further intervention such as branch vessel stenting, thrombolysis, or thromboembolectomy. Endovascular fenestration with or without stenting with ancillary procedures such as thrombolysis can resolve both dynamic and static obstructions⁶ in one setting. Therefore, multiple options are available for the treatment of complicated TBAD; however, the optimal strategy remains uncertain and will depend on the mechanism of obstruction. Herein we report a systematic review to evaluate the different treatment strategies for TBAD complicated by MesMP syndrome.

METHODS

A systematic review was conducted of published literature on surgical or endovascular interventions performed for TBAD complicated by MesMP. This study was deemed exempt from formal institutional review by the institutional review board because identifiable human subjects were not studied. A systematic review of published literature on TBAD-MesMP was performed in adherence to the Preferred Reporting Items for Systematic Review and Meta-Analysis guidelines.¹³ Microsoft Excel (Microsoft) was used during article selection and data extraction. The present study encompasses peer-reviewed articles written in English.

Literature Search Strategy

The PubMed database (including articles indexed in Medline), Web of Science, and Ovid were searched from 1980 until 2020. The search was performed using varying combinations of the following key words: "TBAD," or "CTBAD," or "complicated type B," or "aortic dissection," and "visceral malperfusion," or "visceral ischemia," or "mesenteric malperfusion," or "mesenteric ischemia," or "renal malperfusion," or "renal ischemia," or "bowel malperfusion," or "bowel ischemia."

Eligibility Criteria

Upon completion of the literature search, article selection was executed in a 2-step approach involving abstract review, followed by full-text review. First, any publications gathered during the primary literature search were grouped by title, and duplicates were removed. Subsequently, each abstract was assessed for relevance by 2 of the authors, and any interauthor disagreement concerning article relevance was discussed between the authors; if agreement could not be reached, the article was arbitrated by the senior corresponding author. Exclusion criteria during the abstract review phase are outlined in the Preferred Reporting Items for Systematic Review and Meta-Analysis flow diagram (Figure 1); studies were excluded for the following reasons: (1) study did not report type B aortic dissection; (2) study did not report patients who had visceral ischemia as a presenting sign; (3) study did not report an endovascular or surgical intervention; (4) study was unrelated, that is, involving ischemia of nonaortic etiology, interventions on non-native aorta, laboratory measurement studies, diagnostic techniques, or animal or in vitro studies; (5) study abstract was not written in English; (6) study was a conference abstract, letter to editor, commentary, review article, or meta-analysis article; or (7) study abstract was unavailable. In some instances, studies that did not explicitly state our inclusion criteria but were suggestive thereof were advanced to full-text review for further evaluation.

Any study of humans involving the performance of surgical or endovascular intervention with measured outcomes of effectiveness and efficacy

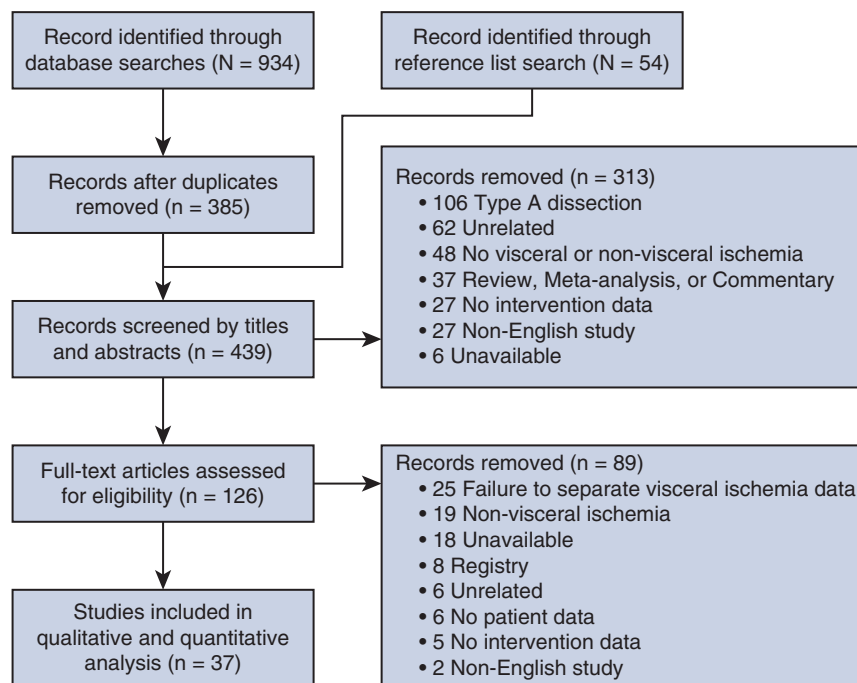


FIGURE 1. PRISMA flow diagram documenting the selection process for articles included in the meta-analysis. No TBAD category includes papers focused on: TAAAD, or non-A non-B aortic dissection. Unrelated category includes papers focused on: ischemia of non-aortic etiology, interventions on non-native aorta, laboratory measurement studies, diagnostic techniques, or animal or in-vitro studies. *PRISMA*, Preferred Reporting Items for Systematic Review and Meta-Analysis; *TBAD*, type B aortic dissection; *TAAAD*, type A aortic dissection.

was moved into the second phase of article selection. Exclusion criteria for full-text review were as follows: (1) study failed to separate type B and type A or non-A non-B dissection data; (2) study failed to separate mesenteric ischemia from renal ischemia; (3) study full-text did not report patients who had mesenteric ischemia as a presenting sign; (4) study full-text did not report a surgical or endovascular intervention; (5) the study full-text was unrelated as described in abstract review criteria; (6) the study used national or international registry data; (7) the study full-text was not written in English; (8) the study failed to present patient-level data; (9) the study full-text was unavailable; and (10) the study failed to present in-hospital mortality. Potentially duplicated cohorts by the same authors were avoided by extensively reviewing study periods, patient selection methods, patient characteristics, and procedural/surgical technique. In these situations, the study with the largest patient cohort was chosen. When there was disagreement regarding article inclusion, a third author was consulted. No new studies were identified when the reference lists of these full-text studies were reviewed. Studies were carefully reviewed to ensure that there were no overlapping patient populations.

Analysis Techniques

Demographic and independent variables extracted include male to female ratio, age, type of aortic dissection treated (acute vs chronic), clinical presentation (ie, additional types of ischemic syndromes), and type of intervention. Retrospective chart review of previously published data from a single institution was performed to identify demographic variables that were not available in the published manuscript. Outcome (dependent) measures recorded include in-hospital mortality, need for additional surgeries, need for bowel resection, and length of stay.

Statistical analysis was performed using SPSS, version 25 (IBM Corp). The Fisher exact test was used for comparison of all categorical variables. The Mann-Whitney *U* test was used to compare distributions of age in the endovascular and surgical treatment groups. Since some of the articles in

the analysis had more than 1 patient, a binary logistic regression was performed with article as random effect and type of intervention (endovascular vs surgical) as fixed binary variable to look for possible association of outcome among patients from the same article.

RESULTS

Studies Meeting Inclusion Criteria

In total, 385 articles were identified, of which 348 were excluded (Figure 1). No randomized controlled trials were found comparing the various surgical and endovascular treatment options for MesMP syndrome associated with type B aortic dissection. Review of the bibliographies of included articles yielded 54 additional studies. In total, 37 articles comprising 10 retrospective reviews and 27 case reports were included. A summary of these studies is provided in Table 1, and their respective outcomes in Table 2.

Demographics and Presentation

In total, 149 patients with MesMP (117 male/31 female; median age 55.0 years (interquartile range [IQR] 46.5-65 years)) were identified in the study. The cohort comprised 148 adults and 1 pediatric patient, an 11-year-old female (Leprince and colleagues²⁰). The etiology of type B aortic dissection was only reported in 73% of studies, with the most common reported cause being hypertension/idiopathic. Two patients had Marfan syndrome (Payabyab and colleagues,²⁴ Wang and colleagues⁴⁰), and

TABLE 1. Patient and study demographics

Study	Type of study	Total patients in study	Total patients with MesMP	Median age, y	Sex ratio (M:F)	Etiology	Chronicity	Clinical presentation	Additional malperfusion?
Shiya et al, 2007 ¹⁴	RCS	51	1	55	1:0	N/P	Acute	N/P*	R
Miyachi et al, 2014 ¹⁵	CR	1	1	48	1:0	HTN	Acute	Back pain, elevated LFTs	No
Suzuki et al, 2015 ¹⁶	CR	1	1	50	1:0	HTN	Acute	Acute back/chest pain, normal labs	No
Yamakado et al, 1998 ¹⁷	CR	1	1	58	1:0	HTN	Acute	Severe abdominal pain	No
Yoshiga et al, 2015 ¹⁸	CR	1	1	69	1:0	HTN, hx of EVAR	Acute	Worsening abdominal pain and melena	LE
Kazimerczak et al, 2018 ¹⁹	CR	1	1	11	0:1	Idiopathic (no marfanoid features)	Acute	Chest pain, peritonitis, sepsis	R
Leprince et al, 2004 ²⁰	CR	1	1	63	unk	N/P	Acute	Abdominal pain	No
Ito et al, 2003 ²¹	CR	1	1	72	1:0	HTN	Acute	Paralytic ileus and occult blood in gastric drainage	R + LE
Bao et al, 2010 ²²	CR	1	1	50	1:0	N/P	Acute	Acute abdominal pain	No
Chang et al, 2001 ²³	CR	1	1	69	1:0	HTN	Acute	Severe abdominal pain, ileus	R + LE
Payabyab et al, 2017 ²⁴	CR	1	1	29	0:1	MFS, HTN	Acute on chronic	Acute abdominal pain	No
Petrilli et al, 2013 ²⁵	CR	1	1	46	0:1	N/P	Acute	Acute abdominal pain	LE
Santo et al, 2007 ²⁶	CR	1	1	56	0:1	N/P	Acute	Elevated LFTs, back pain	R
Son et al, 2012 ²⁷	CR	1	1	76	0:1	N/P	Acute	Abdominal pain	R
Iyer et al, 2009 ²⁸	CR	1	1	77	1:0	HTN, hx of EVAR	Acute	Abdominal pain, elevated lactate, LFTs, amylase	R + LE
Verhoye et al, 2008 ²⁹	RCS	16	3	40 (40-46)	1:2	HTN	Acute	Variable	LE (1), R + LE (1)
Slonim et al, 1996 ³⁰	RCS	9	5	47 (42-62)	3:2	HTN	3 Acute 2 Chronic	Variable	R + LE (2)
Sfyroeras et al, 2011 ³¹	RCS	23	5	63 (60-71)	4:1	HTN	Acute	Variable	R (1), R + LE + S (1)
Lai et al, 2018 ³²	CR	1	1	52	1:0	HTN	Acute	Intermittent abdominal pain	R
Filippone et al, 2013 ³³	CR	1	1	67	1:0	HTN	Acute	Persistent abdominal pain	No
Howell et al, 1997 ³⁴	CR	1	1	40	1:0	HTN	Acute	Abdominal pain, bloody stool, perforated colon on CT	R

(Continued)

TABLE 1. Continued

Study	Type of study	Total patients in study	Total patients with MesMP	Median age, y	Sex ratio (M:F)	Etiology	Chronicity	Clinical presentation	Additional malperfusion?
Kalangos et al, 2014 ³⁵	CR	1	1	47	0:1	HTN	Acute	Persistent abdominal pain	R
Kuo et al, 2013 ³⁶	CR	1	1	58	1:0	HTN	Acute	Back and abdominal pain, elevated LFTs	R + LE
Kurumisawa et al, 2015 ³⁷	CR	1	1	56	1:0	HTN	Acute	Acute abdominal pain, elevated LFTs and lactate	R
Okada et al, 2005 ³⁸	CR	1	1	75	0:1	N/P	Acute	Acute abdominal pain	LE
Saitoh et al, 2012 ³⁹	CR	1	1	68	1:0	N/P	Acute	Severe acute back and abdominal pain	No
Wang et al, 1999 ⁴⁰	CR	1	1	32	0:1	MFS, HTN	Acute	Severe abdominal pain, vomiting, and bloody diarrhea	LE
Yamashiro et al, 2004 ⁴¹	CR	1	1	63	1:0	HTN	Acute	Severe abdominal pain	No
Kim et al, 2014 ⁴²	CR	1	1	78	1:0	Ascending aorta replacement, HTN	Acute	Severe back and abdominal pain	LE
Trimarchi et al, 2010 ⁴³	RCS	21	4	54 (52-56)	4:0	HTN	Acute	Variable	R (2), LE (1)
Williams et al, 1990 ⁵	CR	1	1	46	1:0	HTN	Acute	Severe back pain	LE
Axtell et al, 2020 ⁴⁴	CR	3	3	58 (39, 76)	3:0	N/P	Acute	N/P*	No
Panneton et al, 2000 ⁴⁵	RCS	11	2	72 (68, 76)	1:1	HTN	Acute	Variable	R (1), R + LE (1)
Lauterbach et al, 2001 ⁴⁶	RCS	187	8	50 (45, 57)	8:0	N/P	Acute	N/P*	R (1), LE (1), R + LE (3)
Uchida et al, 2009 ⁴⁷	RCS	130	15	63 (53, 72)	9:6	N/P	Acute	Variable	LE (4), R + LE (4)
Vedantham et al, 2003 ⁴⁸	RCS	11	4	46 (41, 51)	4:0	HTN (4), cocaine (1)	Acute	Severe abdominal pain, GI bleeding (1), metabolic acidosis (3)	R (1), R + LE (3)
Norton et al, 2020 ⁶	RCS	182	73	53 (46, 61)	62:11	N/P	Acute	Variable	R (17), LE (10), R + LE (36), S (1)

MesMP, Mesenteric malperfusion; M, male; F, female; RCS, retrospective case series; N/P, not provided; CR, case report; HTN, hypertension; LFT, liver function test; hx, history; EVAR, endovascular aortic repair; LE, lower extremity; R, renal; unk, unknown; MFS, Marfan syndrome; CT, computed tomography; GI, gastrointestinal; S, spinal. *For Shiya et al. 2007, and Axtell et al. 2020, the clinical presentation for mesenteric malperfusion was not provided.

1 patient reportedly was using cocaine before the dissection (Vedantham and colleagues⁴⁸). There were no reported cases of aortic dissection secondary to trauma. Three

patients had a previous history of aortic surgery for aneurysmal disease (Yoshiga and colleagues,¹⁸ Iyer and colleagues,²⁸ and Kim and colleagues⁴²). The aortic

TABLE 2. Procedural and clinical outcomes

Study	Total patients with MesMP	Intervention	Clinical success (%)	IHM	Additional surgery/procedure?	Need for bowel resection?	Major complications	LOS, d, median (first, third quartile)	Follow-up, mo
Shiya et al, 2007 ¹⁴	1	BS (SMA)	100	0	Diagnostic laparoscopy	N	N	N/P	N/P
Miyachi et al, 2014 ¹⁵	1	E-Fen + AS	100	0	N	N	N	21	12
Suzuki et al, 2015 ¹⁶	1	BS (SMA)	100	0	Diagnostic laparoscopy; total arch replacement	N	Conversion to TAAD on POD7	90	24
Yamakado et al, 1998 ¹⁷	1	BS (SMA)	100	0	N	N	N	30	12
Yoshiga et al, 2015 ¹⁸	1	TEVAR	100	0	N	N	N	N/P	6
Kazimerczak et al, 2018 ¹⁹	1	TEVAR + BS (SMA)	100	0	N	N	Intraprocedural PEAs, but ROSC	21	N/P
Leprince et al, 2004 ²⁰	1	TEVAR	100	0	N	N	N	N/P	3
Ito et al, 2003 ²¹	1	AS	100	0	N	N	N	N/P	19
Bao et al, 2010 ²²	1	TEVAR	100	0	Exploratory laparotomy	Y	N	N/P	N/P
Chang et al, 2001 ²³	1	TEVAR	100	0	N	N	N	N/P	2
Payabyab et al, 2017 ²⁴	1	TEVAR	100	0	N	N	N	4	N/P
Petrilli et al, 2013 ²⁵	1	TEVAR	100	0	N	N	N	N/P	N/P
Santo et al, 2007 ²⁶	1	TEVAR	0	1	N	N	TAAD and intrapericardial rupture with cardiac arrest, death on POD14	14	N/P
Son et al, 2012 ²⁷	1	TEVAR	100	0	N	N	N	16	12
Iyer et al, 2009 ²⁸	1	TEVAR	100	0	N	N	N	21	11
Verhoye et al, 2008 ²⁹	3	3 TEVAR	66.7	1	Exploratory laparotomy (1)	Y	Multiorgan failure (1)	N/P	N/P
Slonim et al, 1996 ³⁰	5	1 AS 1 AS + BS (SMA) 2 E-Fen 1 E-Fen + AS	100	0	Exploratory laparotomy (1)	Y	Acute renal failure (1)	N/P	N/P
Sfyroeras et al, 2011 ³¹	5	5 TEVAR	60	2	N	N	Respiratory failure (2)	8.5 (4.8, 12.5)	12
Lai et al, 2018 ³²	1	BS (CA)	100	0	N	N	N	N/P	1

(Continued)

TABLE 2. Continued

Study	Total patients with MesMP	Intervention	Clinical success (%)	IHM	Additional surgery/procedure?	Need for bowel resection?	Major complications	LOS, d, median (first, third quartile)	Follow-up, mo
Filippone et al, 2013 ³³	1	OAR (Graft) + S-Fen	100	0	N*	N	N	N/P	12
Howell et al, 1997 ³⁴	1	OAR (Graft)	100	0	N*	Y	N	N/P	12
Kalangos et al, 2014 ³⁵	1	E Fen + BS (SMA) + DB (Ao-SMA)	100	0	N	N	N	21	16
Kuo et al, 2013 ³⁶	1	IDB (Ax-Fem)	100	0	N	N	N	21	14
Kurumisawa et al, 2015 ³⁷	1	OAR (S-Fen)	100	0	N*	N	N	16	N/P
Okada et al, 2005 ³⁸	1	DB (LEIA-Ileocolic + LEIA-GEA)	100	0	N	N	N	N/P	7
Saitoh et al, 2012 ³⁹	1	OAR (S-Fen)	100	0	N*	Y	N	N/P	N/P
Wang et al, 1999 ⁴⁰	1	OAR (Graft)	100	0	Additional exploratory laparotomy	Y†	N	N/P	N/P
Yamashiro et al, 2004 ⁴¹	1	DB (RCIA-SMA and GDA)	100	0	N*	N	N	N/P	12
Kim et al, 2014 ⁴²	1	IDB (Fem-Fem then Ax-Fem bypass)‡	100	0	N	N	N	N/P	12
Trimarchi et al, 2010 ⁴³	4	4 OAR (S-Fen)	75	1	N	N	Multiorgan failure (1)	N/P	192 (138, 216)
Williams et al, 1990 ⁵	1	E Fen	100	0	N	N	Chronic mesenteric ischemia	35	NP
Axtell et al, 2020 ⁴⁴	3	1 hybrid§ 2 hybrid§ + BS (SMA)	100	0	N	N	CVA (1)	15.0 (12.5, 21.5)	N/P
Panneton et al, 2000 ⁴⁵	2	1 OAR (S-Fen + graft) 1 TEVAR + E-Fen	50	1 (patient with OAR)	N	N	Acute renal failure (1)	N/P	N/P
Lauterbach et al, 2001 ⁴⁶	8	6 OAR (S-Fen) 1 E-Fen + BS (SMA) 1 OAR (Graft)	87.5	1 (patient with E-fen + BS)	N*	Y (1)	Multi-organ failure (1), Permanent dialysis (1)	17.5 (15, 28)	N/P
Uchida et al, 2009 ⁴⁷	15	1 TEVAR 2 BS (CA/SMA, SMA) 10 OAR (8 AS, 2 S-Fen) 2 DB (SMA)	80	3 (1 TEVAR, 2 OAR)	N*	Y (1)	Multi-organ failure (2), Intra-operative aortic injury from sheath during TEVAR (1)	N/P	45 (16, 60)

(Continued)

TABLE 2. Continued

Study	Total patients with MesMP	Intervention	Clinical success (%)	IHM	Additional surgery/procedure?	Need for bowel resection?	Major complications	LOS, d, median (first, third quartile)	Follow-up, mo
Vedantham et al, 2003 ⁴⁸	4	2 AS + E-Fem 1 AS 1 E-fen	100	0	N	N	N	N/P	N/P
Norton et al, 2020 ⁶	73	40 E-Fem + BS 17 E-Fem + AS 11 BS 1 E-Fem 2 AS + BS 1 TEVAR + BS 1 TEVAR	87.7	9 (7 E-Fem + BS, 1 E-Fem + AS 1 BS)	Exploratory laparotomy (10) DTAR (1)	Y (8)	N/P	11.0 (8, 20)	N/P

MesMP, Mesenteric malperfusion; IHM, in-hospital mortality; LOS, length of stay; BS, branch vessel stenting; SMA, superior mesenteric artery; N, no; N/P, not provided; E-Fem, endovascular fenestration; AS, aortic stenting; TAAO, type A aortic dissection; POD, postoperative day; TEVAR, thoracic endovascular aortic repair; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; Y, yes; CA, celiac artery; OAR, open aortic repair; DB, direct bypass; Ao, aorta; IDB, indirect bypass; Fem-Fem, femoral to femoral artery bypass; Ax-Fem, axillary to femoral artery bypass; S-Fem, surgical fenestration; LEIA, left external iliac artery; GEA, gastropiploic artery; RCIA, right common iliac artery; GDA, gastroduodenal artery; CVA, cerebrovascular accident; DTAR, descending thoracic aortic repair. #Bowel inspected during OAR. †Exploratory laparotomy with bowel resection and primary anastomosis performed at outside hospital prior to transfer and aortic repair. ‡Planned fenestration and stenting cancelled due to resolution of ischemic signs following IDB. §Open total arch replacement with FET.

dissection was classified as acute in 98% (146/149) of cases, acute-on-chronic in 0.7% (1/149) of cases, and chronic in 1.3% (2/149) of cases.

Clinical presentation was reported in 91.8% (34/37) of studies. Presentation and symptoms are reported in Table 1. The most common symptom in patients with MesMP was abdominal pain. Other concomitant clinical and radiographic malperfusion are reported in Table 1. MesMP was the sole ischemic complication in 26% (38/149) of patients and was accompanied by renal malperfusion alone in 22.1% (33/149) of patients, lower-extremity malperfusion alone in 15.4% (23/149), and both renal and lower-extremity malperfusion in 36.9% (55/149).

Treatment

Surgical and endovascular treatments were performed in 35 of 149 (23.5%) and 112 of 149 (75.2%) patients, respectively, whereas 2 patients (1.3%) had combination procedures. In the surgical group, open aortic reconstruction (open fenestration, open stenting, or open aortic replacement with graft), direct anatomic bypass, or indirect anatomic bypass were performed in 29 of 35 (82.8%), 4 of 36 (11.4%), and 2 of 35 (5.7%) cases, respectively. In the endovascular group, a thoracic endograft or an aortic stent alone was placed in 22 of 112 (19.6%) of cases, percutaneous fenestration alone was performed in 5/112 (4.5%) of cases, and branch stenting alone was performed in 17 of 112 (15.2%) of cases. A combination of TEVAR or aortic stent + fenestration, TEVAR or aortic stent + branch stenting, or fenestration + branch stenting was performed in 22 of 112 (19.6%), 5 of 112 (4.5%), 41 of 112 (36.6%), and of cases, respectively. Overall, 43.7% (49/112) of patients had only aortic interventions, whereas 56.3% (63/112) required a branch vessel intervention. Two patients had combination procedures, including one patient who had aortic fenestration then 6 hours later an SMA stent placed immediately followed by open direct anatomic bypass (n = 1)³⁵ and 1 patient an open ascending/arch replacement with frozen elephant trunk and branch vessel stenting (n = 1).⁴⁴ Preoperative demographics, including age, sex, and dissection type, were similar between the endovascular and open repair groups. Concomitant renal, lower extremity, or renal + lower-extremity malperfusion was also similar between these 2 groups (Table 3).

Procedural/Surgical Outcomes

Overall in-hospital mortality was 12.8% (19/149). A summary of procedural and clinical outcomes is provided in Table 2. Clinical success, defined as resolution of malperfusion without in-hospital mortality, was similar between surgical and endovascular approaches (86.1% vs 84.4%) as was in-hospital mortality (11.4% vs 13.4%, P = .762). Necessity for bowel resection was also similar between surgical and endovascular approaches (14.3% vs 9.8%,

TABLE 3. Demographics, procedures, and outcomes among the open and endovascular repair treatment strategies for TBAD and MesMP

	Total (n = 149)	Open repair (n = 35)	Endovascular repair (n = 112)	P value
Demographics				
Age	55 (46, 65)	57 (48, 68)	53.5 (46, 63)	.103
Sex, male	117 (79)	28 (80)	88 (79)	.532
Dissection type				
Acute	146 (98)	35 (100)	109 (97)	
Acute-on-chronic	1 (0.7)	0 (0)	1 (0.9)	.439
Chronic	2 (1.3)	0 (0)	2 (1.8)	
Additional malperfusion				
Renal	33 (22)	5 (14)	26 (23)	
Lower extremity	23 (15)	9 (26)	14 (12.5)	.074
Renal + lower extremity	55 (37)	9 (26)	46 (41)	
Procedure				
Aortic fenestration	87 (58)	16 (46)	70 (62.5)	.059
Aortic stenting	40 (27)	10 (29)	29 (26)	.455
Branch vessel stenting*	48 (32)	1 (2.9)	45 (40)	<.005
Open aortic replacement	9 (6.0)	7 (20)	0 (0)	<.005
Open bypass*	5 (3.4)	4 (11)	0 (0)	.003
Outcomes				
Bowel resection	17 (11)	5 (14)	11 (9.8)	.267
In-hospital mortality	19 (13)	4 (11)	15 (13)	.509

Data presented as median (25%, 75%) for continuous data and n (%) for categorical data. *TBAD*, Type B aortic dissection; *MesMP*, mesenteric malperfusion. *Branch vessel stenting and open bypass for the treatment of mesenteric malperfusion, stenting and bypass for other vascular territories not included.

$P = .459$) (Table 3). Within the surgical approach group (n = 35), systemic complications included multiorgan failure (n = 3), and acute renal failure (n = 2). Within the

endovascular approach group (n = 112), systemic complications included conversion to type A dissection during TEVAR (n = 2), intraoperative aortic injury from sheath during

TABLE 4. Demographics, procedures, and outcomes among surgical strategies for TBAD and MesMP

	Total (n = 35)	Open aortic replacement (n = 7)	Open fenestration or stenting (n = 21)	Vascular bypass or other* (n = 7)
Demographics				
Age	57 (48, 68)	57 (40, 63)	56 (47, 65)	68 (61, 77)
Sex, male	28 (80)	6 (86)	16 (76)	6 (86)
Dissection type				
Acute	35 (100)	7 (100)	21 (100)	7 (100)
Acute-on-chronic	0 (0)	0 (0)	0 (0)	0 (0)
Chronic	0 (0)	0 (0)	0 (0)	0 (0)
Additional malperfusion				
Renal	5 (14)	2 (29)	3 (14)	0 (0)
Lower extremity	9 (26)	1 (14)	6 (29)	2 (29)
Renal + lower extremity	9 (26)	2 (29)	5 (24)	2 (29)
Procedure				
Aortic fenestration	16 (46)	2 (29)	13 (62)	0 (0)
Aortic stenting	10 (29)	2 (29)	8 (38)	0 (0)
Branch vessel stenting†	1 (2.9)	1 (14)	0 (0)	0 (0)
Open aortic replacement	7 (20)	7 (100)	0 (0)	0 (0)
Open bypass†	4 (11)	0 (0)	0 (0)	4 (57)
Outcomes				
Bowel resection	5 (14)	3 (43)	0 (0)	2 (29)
In-hospital mortality	4 (11)	1 (14)	3 (14)	0 (0)

Data presented as median (25%, 75%) for continuous data and n (%) for categorical data. *TBAD*, Type B aortic dissection; *MesMP*, mesenteric malperfusion. *Other includes branch vessel thrombectomy, branch vessel fenestration, and branch vessel patch repair. †Branch vessel stenting and open bypass for the treatment of mesenteric malperfusion, stenting and bypass for other vascular territories not included.

TABLE 5. Demographics, procedures, and outcomes among open endovascular strategies for TBAD and MesMP

	Total (n = 112)	Any TEVAR (n = 21)	Fenestration/stenting w/o TEVAR (n = 91)	P value
Demographics				
Age	53.5 (46, 63)	60 (46, 69)	53 (46, 61)	.405
Sex, male	88 (79)	11 (55)	77 (85)	<.005
Dissection type				.215
Acute	109 (97)	20 (95)	89 (98)	
Acute-on-chronic	1 (0.9)	1 (4.8)	0 (0)	
Chronic	2 (1.8)	0 (0)	2 (2.2)	
Additional malperfusion				.558
Renal	26 (23)	4 (19)	22 (24)	
Lower extremity	14 (12.5)	4 (19)	10 (11)	
Renal + lower extremity	46 (41)	5 (24)	41 (45)	
Procedure				
Aortic fenestration	70 (62.5)	0 (0)	70 (77)	<.005
Aortic stenting	29 (26)	2 (9.5)	27 (30)	.094
Branch vessel stenting*	45 (40)	2 (9.5)	43 (47)	<.005
Outcomes				
Bowel resection	11 (9.8)	2 (9.5)	9 (9.9)	.999
In-hospital mortality	15 (13)	5 (24)	10 (11)	.153

Data presented as median (25%, 75%) for continuous data and n (%) for categorical data. TEVAR, Thoracic endovascular aortic repair; TBAD, type B aortic dissection; MesMP, mesenteric malperfusion. *Branch vessel stenting for the treatment of mesenteric malperfusion, stenting and bypass for other vascular territories not included.

TEVAR (n = 1), multiorgan failure (n = 2), respiratory failure (n = 2), acute renal failure (n = 1), and subacute ischemic infarcts with right-sided weakness (n = 1). Among the 2 patients receiving combination procedures, 50% (1/2) required a bowel resection and in-hospital mortality was 0%.

Within the surgical approaches, bowel resection was performed in 42.9% (3/7) of patients undergoing open aortic replacement, 0% (0/21) of patients undergoing open aortic fenestration or stenting, and 28.6% (2/7) of patients

undergoing open bypass or other open procedure. In-hospital mortality was 14.3% in the open aortic replacement group, 14.3% in the open aortic fenestration or stenting group, and 0% in the open bypass or other open procedure group (Table 4). Statistical testing evaluating significance of difference between these subgroups was not performed given the small sample size and bias associated with multiple testing. Within the endovascular approaches, necessity for bowel resection was similar between any TEVAR and fenestration/stenting without TEVAR groups

TABLE 6. Logistic regression of study author and intervention on in-hospital mortality

	Coefficient	Standard error	Wald test	P value
Intervention	1.121	1.154	0.944	.331
Endovascular				
Surgical	1.121	1.154	0.944	.331
Study			5.815	.758
Verhoye et al, 2008 ²⁹				
Slonim et al, 1996 ³⁰	19.060	28,421.33	0.000	.999
Sfyroeras et al, 2011 ³¹	18.120	28,421.33	0.000	.999
Trimarchi et al, 2010 ⁴³	20.642	28,421.33	0.000	.999
Panneton et al, 2000 ⁴⁵	19.676	28,421.33	0.000	.999
Lauterbach et al, 2001 ⁴⁶	-1.121	33,628.37	0.000	1.000
Uchida et al, 2009 ⁴⁷	20.104	28,421.33	0.000	.999
Vedantham et al, 2003 ⁴⁸	19.533	28,421.33	0.000	.999
Norton et al, 2020 ⁶	-1.121	34,808.63	0.000	1.000
Axtell et al, 2020 ⁴⁴	19.388	28,421.33	0.000	.999

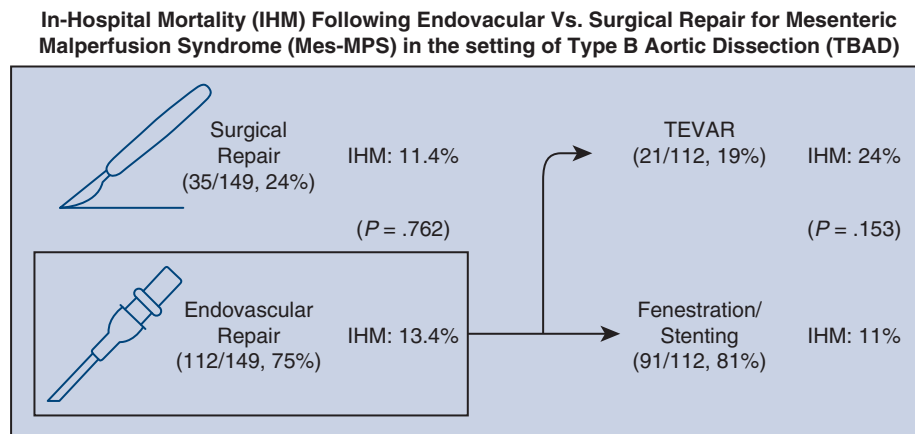


FIGURE 2. Diagram depicting the in-hospital mortality (IHM) of surgical repair (11.4%) versus endovascular repair (13.4%). Within the endovascular repair group (n = 112), in-hospital mortality was 24% in the TEVAR group versus 11% in the fenestration/stenting group. TEVAR, Thoracic endovascular aortic repair; MesMP, mesenteric malperfusion; TBAD, type B aortic dissection.

(9.5% vs 9.9%, $P = .999$), while in-hospital mortality was greater in the any TEVAR group (24% vs 11%) although not statistically significant ($P = .153$) (Table 5).

Logistic regression did not demonstrate a significant relationship between the article published or type of intervention (endovascular vs surgery) with in-hospital mortality, P values of .758 and .331, respectively (Table 6).

Length of stay was presented in 16 studies, which corresponded to pooled median of 12.5 days (IQR, 8-21 days) (n = 98). Twenty studies reported data on how long they followed patients, which corresponded to a pooled median of 16 months (IQR, 12-49.5 months) (n = 38).

DISCUSSION

In this systematic review, we analyzed type B aortic dissection complicated by MesMP and the variety of strategies for the management of this serious condition. We found that TBAD + MesMP was managed endovascularly in 75% of cases, surgically in 23%, and with open + endovascular combination in 2% of cases (Figure 2). Bowel resection was performed in 11% of patients, and overall in-hospital mortality was 12.8% and was similar between endovascular and surgical strategies (13% vs 11%). This study underscores the severity of TBAD with MesMP as well as many different management strategies. A summary of the findings, as well as an example case of endovascular management of TBAD + MesMP is presented in the Video Abstract.

The management of aortic disease has seen an evolution in treatment strategy with the advent of new technologies, in particular endovascular therapies such as stent grafting. The increased use of endovascular therapies as seen in International Registry of Acute Aortic Dissection (IRAD)⁴⁹ was evident in this review, with 71% of cases treated endovascularly through 2007 and 81% of cases after 2007. However, over the past 13 years, ~20% of TBADs with MesMP were managed with an open surgical strategy or combination

endovascular and open strategy. Due to the many treatment strategies available, multiple aspects need to be considered when deciding the optimal strategy for each patient. First, one must consider the capabilities of both institution and physician as well as the working relationship between specialties of interventional radiology, cardiothoracic surgery, vascular surgery, and general surgery. The facility and physician must be comfortable with the chosen strategy. The highly variable strategies presented in this review highlight the differences in practice patterns, with each noncase report manuscript predominantly presenting one treatment option. For example, the studies by Verhoye and colleagues²⁹ and Sfyroeras and colleagues³¹ present TEVAR, the study by Trimarchi and colleagues⁴³ presents open surgical fenestration, the study by Axtell and colleagues⁴⁴ presents a hybrid approach with open total arch replacement and frozen elephant trunk placement, and the study by Norton and colleagues⁶ presents endovascular fenestration/stenting. Second, the specific patient must be considered, including age, sex, comorbidities, dissection characteristics and extent, vascular territories malperfused, and type of malperfusion.

As pioneered by Williams and colleagues,⁵ obstruction caused by aortic dissection can be static, dynamic, or a combination of the two, with the different etiologies determining treatment strategy. Dynamic obstruction results from the dissection flap of a collapsed true lumen prolapsing across the orifice of a branch vessel, such as the SMA, prohibiting flow into the branch vessel. Dynamic obstruction can be intermittent and vary in severity depending on the blood pressure. Static obstruction results from extension of dissection into a branch vessel without adequate re-entry, often causing false lumen thrombosis in the branch artery. While dynamic obstruction can be treated with open aortic repair or TEVAR with covering of the intimal tear, static obstruction usually requires targeted branch vessel

intervention such as branch vessel stenting, thrombolysis, or thromboembolectomy. Therefore, the first step in managing TBAD with suspected MesMP (which presumes the physicians have some imaging confirmation of the dissection and some appreciation of the ongoing mechanism of possible obstruction) should be blood pressure control to limit severity of dynamic obstruction. In this review, 32% of patients required branch vessel stenting, and 3% had a direct vascular bypass, suggesting the presence of static obstruction. However, this is much lower than that reported in patients with TBAD and visceral malperfusion in an IRAD study,⁴⁹ in which ~80% had evidence on CT scan of branch vessel involvement. Among those undergoing endovascular management, branch vessel stenting was much more prevalent in the fenestration/stenting group compared to the TEVAR group (47% vs 9.5%, $P < .005$). Therefore, in patients in which static obstruction is suspected (ie, those with branch vessel involvement on CT), endovascular fenestration/stenting could be the preferred strategy so that both dynamic and static obstruction can be addressed at the time of intervention.

With each patient in mind, risks of each procedure should be considered. For an open strategy, can a patient tolerate that open procedure? The strategy of open arch replacement with frozen elephant trunk requires cardiopulmonary bypass and crossclamping of the aorta. TEVAR requires an adequate landing zone and has associated risks, including retrograde type A dissection ($n = 2$ in this survey), risk of paralysis (not captured in this review) due to false lumen or intercostal artery thrombosis (not reported with fenestration/stenting⁶), and determining if it can resolve the malperfusion, especially if there is static obstruction, and risk of graft infection, especially in the presence of dead bowel. Fenestration/stenting allows quick assessment of hemodynamics and enables each branch vessel to be investigated,⁵⁰ but it requires expertise from interventional radiology and is not available at all hospitals. Complications of infradiaphragmatic arterial obstruction in this study, including renal failure and multisystem organ failure, were present in patients treated by both surgical and endovascular strategies. Two patients (1.8%) who underwent endovascular management, both TEVAR, suffered conversion to type A dissection. Each intervention and associated risks need to be considered for each specific individual patient, and the selected strategy should be tailored to the patient. In addition, the available physician and treatment team partially determines the choice of treatment. For example, if a cardiac surgeon is managing the patient, TEVAR is a valid option, but if an interventional radiologist is on the aortic team, then endovascular fenestration/stenting is also an option. Ideally, all of the treatment strategies are tools in the toolbox in the management of TBAD with MesMP, and the optimal treatment strategy will vary by facility, physician, and patient.⁵⁰ Hospitals can consider

incorporating a MesMP response team to get all experts on board and decide on a patient-specific treatment, as numerous hospitals have done for the management of pulmonary embolism.^{51,52}

Following visceral reperfusion, a surgical consult should be placed to determine whether diagnostic laparoscopy/exploratory laparotomy is required, as it has been shown to decrease mortality.⁵³ Discriminating between adequate and inadequate mesenteric perfusion by visual and manual inspection of the bowel is more reliable after endovascular relief of obstruction of the SMA. In some circumstances, local surgical and endovascular facilities can enable bowel inspection at the time of reperfusion, as seen in included reports.^{33,34,37,39,41,47} In total, 17% (25/149) underwent diagnostic laparoscopy/exploratory laparotomy and bowel inspection, and 11% (17/149) underwent bowel resection, with similar rates of bowel resection among endovascular and open surgical strategies (10% vs 14%).

The overall in-hospital mortality of 13% for MesMP in this review is likely underestimated secondary to publication bias, since any visceral ischemia in the setting of TBAD is associated with a mortality of 31% per IRAD data.⁴⁹ Variable institutional definitions of malperfusion may also affect IHM. Endovascular and surgical management groups had similar mortality (11% vs 13%) in this cohort of TBAD with MesMPS, underscoring the severity of MesMPS in the setting of TBAD. In addition, malperfusion of additional vascular territories is associated with an increase in mortality.⁵⁴

This study is limited by available data and reported outcomes in manuscripts; therefore, more specific complication rates and hospital lengths of stay were unable to be determined. This study is also limited by sample size with a possibility of type II error. There are currently no standard guidelines for reporting of clinical outcome measures or mortality data, and thus a more general definition of in-hospital mortality was used as described above and no time-dependent patient outcomes, such as 30-day mortality, were analyzed. We hope this study serves as an impetus for future studies to present this data. In addition, the anatomical spectrum of SMA obstruction is not reported in most reviews, which limits comparison of mechanisms. There are currently no large prospective data sets comparing combinations of endovascular modalities, especially in the treatment of complicated TBAD. Future studies that compare these modalities, specifically looking at static versus dynamic malperfusion, are warranted.

CONCLUSIONS

Type B aortic dissection complicated with MesMP is a serious condition with open, endovascular, and hybrid treatment strategies available. Necessity for bowel resection and in-hospital mortality was similar between open and

endovascular strategies; however, endovascular management is the most commonly used strategy.

Conflict of Interest Statement

M.S.K. reported speaking honoraria from Penumbra, Inc, Boston Scientific, and Medtronic; and grant funding from Boston Scientific, Inc, and the SIR Foundation, none of which are relevant to this paper. D.M.W. reported Medical Advisory Board of Boston Scientific, which is not relevant to this paper. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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