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A Decade's Experience With Temporary Intravascular Shunts at a Civilian Level I Trauma Center

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Background: A 10-year review of temporary intravascular shunts (TIVS) at a regional trauma center.

Methods: Retrospective chart review of all patients treated with temporary intravascular shunts from January 1, 1997 to January 1, 2007.

Results: Seven hundred eighty-six patients were treated for vascular injuries. Sixty-seven (9%) had a total of 101 (72 arterial, 29 venous) TIVS placed to facilitate damage control or to allow for reconstruction of Gustilo IIIc fractures or limb replantation. Seven patients who, on trauma day 0, died or had an extremity which was deemed unsalvageable were excluded. Of 60 patients who met inclusion criteria, seven died from TBI (3%), MOF (3%), sepsis (2%), deceleration of care (2%), and loss of airway (2%), which was deemed preventable.

Conclusions: TIVS have a shunt thrombosis rate of 5%, amputation rate of 18%, overall survival of 88%, and combination limb/patient survival rate of 73%. TIVS have an established role primarily in patients requiring either "damage control" for exsanguination or temporary vascular conduits during stabilization of Gustilo IIIc fractures. Truncal injuries are associated with the highest mortality likely due to accompanying multisystem trauma.

Key Words: Vascular shunts, Vascular injuries, Vascular trauma, Temporary shunts, Vascular damage control.

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Extremity vascular trauma is often associated with not only injuries to the brain and torso, but also with local bony and soft tissue defects. Management of these multiply injured patients can be very challenging, as restoring perfusion to an ischemic extremity needs to be accomplished expeditiously, generally within 6 hours to 8 hours, if function is to be salvaged.[1] In addition to warm ischemia time, other factors which are associated with amputation include: ipsilateral fractures, complex soft tissue destruction, inadequate soft tissue debridement at the time of vascular repair, and nerve injuries.[2–4] During World War II, ligation was the standard treatment and amputation rates approached 50% for patients with peripheral vascular injuries. As vascular repair became more common, this rate subsequently decreased throughout the Korean War, and eventually approached 8% at the end of the Vietnam War.[4] In more recent civilian trauma literature, amputation rates after vascular injuries range from 8% to 24%, including several series of popliteal arterial injuries which are generally perceived as the most morbid of extremity vascular injuries.[5–10]

Although most vascular trauma is repaired at the patient's initial operation, unfavorable patient physiology may require the use of intravascular shunts to temporarily reestablish perfusion to a threatened limb. Also, temporary intravascular shunts (TIVS) may allow for orthopedic fixation and both truncate ischemia time and prevent disruption of tenuous vascular anastomoses during bone stabilization and debridement of soft tissue injuries.[5]

Since the first report of their military use in 1919,[11] TIVS have recently been supported by wartime surgeons in military damage control surgery,[12–14] and their use has also been reported in several small series and case reports from civilian trauma centers.[3,10,15–17] TIVS have been used liberally by the Emory Trauma Service at Grady Memorial Hospital for more than a decade in the management of both peripheral and truncal vascular injuries. The objective of this study was to review our practice pattern of TIVS use in the civilian trauma population, as well as to review the outcome of patients with injuries requiring this therapy.

PATIENTS AND METHODS

The records of 786 patients with vascular injuries treated by the Emory Trauma Service at Grady Memorial Hospital between January 1997 and January 2007 were reviewed. Grady Memorial Hospital is a large public hospital and a state of Georgia Level I trauma center. The study was performed with the approval of the Emory University Institutional Review Board.

Patients were identified in the Trauma Registry of the American College of Surgeons (TRACS), and data were collected by reviewing the patients' medical records, operative logs, and surgical morbidity and mortality conference

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records. Patients who underwent insertion of a TIVS were identified and included in further analysis. The decision to insert a TIVS as well as the decision on what type of shunt employed were at the discretion of the attending trauma surgeon. In all cases, local thrombectomy was performed, and regional heparin was administered to the injured vessel.

We divided the indications for the placement of TIVS into two groups. The first group consisted of patients with physiologic derangement with need for damage control. These patients were generally hypothermic, coagulopathic, and acidotic and, therefore, did not undergo definitive vascular repair at the initial operation. Therefore, they were transferred to the surgical intensive care unit (ICU) for resuscitation with the TIVS in place. This cohort was further divided into truncal and extremity groups with vascular trauma proximal to the common femoral and axillary vessels considered as truncal injuries.

The second group, the nondamage control group, consisted of those patients who had shunts placed and removed at their initial operation in preparation of definitive vascular repairs. This group was further divided into three subgroups. The first subgroup were those with Gustilo IIIc open fractures, which were defined as open fractures with associated arterial injuries requiring repair, irrespective of the degree of soft tissue damage (Fig. 1).[18] If a patient with a Gustilo IIIc fracture left the operating room (OR) with a TIVS, he was placed in the damage control group. The next subgroup was made up of patients who required TIVS for limb perfusion while preparation was being made for definitive vascular repair during the same operation (i.e., need for vein harvest, management of torso injuries). And finally, one patient who needed full replantation, in whom TIVS were used, was also analyzed.

Data collected from available records included the following: demographic information; mechanism of injury; vessel injured; extent of injury; type of TIVS used; indication for shunt; total intraoperative blood products administered; "dwell" time of TIVS in hours; associated injuries; use of fasciotomies; choice of definitive repair; admission hemodynamic, physiologic, and laboratory data; calculated trauma scores, including Injury Severity Score (ISS) and Revised Trauma Score; complications; amputation rate; function of limb; overall survival; and length of stay. All statistical analysis was performed using SPSS Software (SPSS, Chicago, IL) with significance set at $p < 0.05$.

Fig. 1. *Temporary intravascular shunts in popliteal artery and vein with an associated proximal tibia fracture.*

RESULTS

Demographics and Mechanism of Injury

Between January 1997 and January 2007, 20,435 trauma patients were admitted by the Emory Trauma Service, of which 786 (4%) had vascular injuries identified. Of these, 73 patients (9%) had a total of 108 TIVS placed in 76 (70%) arteries and in 32 (30%) veins. Seven patients who died on trauma day 0 or who had an extremity which was deemed ultimately unsalvageable at the initial operation and who underwent primary amputation were excluded from the study. Demographic information for the 66 remaining patients who comprised the study population is listed in Table 1.

Mechanisms of injury are also listed in Table 1. Overall, 42 patients (64%) suffered penetrating wounds, including 41 gunshot wounds (GSW) and one stab wound, whereas 18 patients (27%) required TIVS after blunt shear injuries and 6 (9%) after crush injuries.

TIVS Characteristics

Of the 99 TIVS used, 61 (62%) were Argyle shunts (C.R. Bard, Billerica, MA), 16 (16%) were small caliber chest tubes, and 20 (20%) were Pruitt-Inahara (P-I) shunts (LeMaitre Vascular, Burlington, MA). In addition, one 5 Fr. pediatric feeding tube and one 16 gauge angiocatheter were used.

The most common caliber Argyle shunt that was used was the 14 Fr. Argyle shunt which was employed 30 times in

Table 1 **Demographic Information and Mechanism of Injury**

Demographics	Mean ± SEM
Age (yr)	30 ± 1.5
ISS	15 ± 1.1
RTS	11 ± 0.3
Admission BD	10.7 ± 0.96
Gender	
Male	58 (88%)
Female	8 (12%)
Penetrating	42 (64%)
GSW	41 (62%)
SW	1 (2%)
Blunt	24 (36%)
MVC	8 (12%)
Ped struck	7 (11%)
Crush	6 (9%)
Fall	3 (5%)

BD indicates base deficit; GSW, gunshot wound; ISS, Injury Severity Score; MVC, motor vehicle collision; Ped, pedestrian; RTS, revised trauma score; SEM, standard error of mean; SW, stab wound.

22 patients (30%) with 18 arterial (60%) and 12 venous (40%) injuries. The most frequent injured vessel in which a 14 Fr. Argyle shunt was used was the superficial femoral artery (SFA) (30%). Other vessels which accommodated this shunt were the popliteal artery (POA) (n = 7), popliteal vein (POV) (n = 7), and superficial femoral vein (SFV) (n = 5) (Table 2). Twenty-eight smaller Argyle shunts (28%) were also used successfully, including fourteen 12 Fr., nine 10 Fr., and five 8 Fr. shunts. The longest "dwell" time for an Argyle shunt smaller than a 14 Fr. was 52 hours.

Sixteen CTs were used in 15 patients (16%) with three arterial (3%) and 13 venous (13%) injuries (Table 3). The most frequent vessel in which this type of TIVS was placed was the SFV (n = 7), followed by the POV (n = 4).

Table 2 Utilization of the 14 Fr. Argyle Shunt

Injured Vessel	No. Patients (%)
SFA	9 (30)
POA	7 (23)
POV	7 (23)
SFV	5 (17)
EIA	1 (3)
AxA	1 (3)
Total	30 (100)

SFA indicates superficial femoral artery; POA, popliteal artery; POV, popliteal vein; SFV, superficial femoral vein; EIA, external iliac artery; AxA, axillary artery.

Table 3 Use of Small Caliber CT and Pruitt-Inahara Shunts

	n (%)	
	CT (n = 16)	P-I (n = 20)
No. patients	15 (23%)	18 (27%)
No. arteries shunted	3 (3%)	19 (19%)
No. veins shunted	13 (13%)	1 (1%)
Most common vessels shunted	SFV (n = 7; 44%) POV (n = 4; 25%)	SFA (n = 7; 35%) POA (n = 6; 30%)

CT indicates chest tube; P-I, Pruitt-Inahara shunt; POA, popliteal artery; POV, popliteal vein; SFA, superficial femoral artery; SFV, superficial femoral vein.

Twenty 9 Fr. P-I shunts were employed in 18 patients (27%) with 19 arterial (19%) and 1 venous (1%) injury (Table 3). This type of TIVS most commonly accommodated the SFA (n = 7), followed closely by the POA (n = 6). The only thrombosed TIVS which lead to amputation was a 9 Fr. P-I shunt in the brachial artery of a 56-year-old man with a mangled upper extremity.

Anatomic Distribution of TIVS

The most frequent vessel shunted was the SFA (25%). These vessels were cannulated with nine 14 Fr. Argyle shunts (all males), seven 9 Fr. P-I shunts (all males), and five 12 Fr. Argyle shunts (four males, one female). The distribution of shunts in other vessels is listed in Table 4.

In the upper extremity, the most common vessel shunted was the brachial artery with 10 (10%) such injuries managed in this series (Table 4). One 5 Fr. pediatric feeding tube, three 9 Fr. P-I shunts, three 10 Fr. Argyle and three 12 Fr. Argyle shunts accommodated the injured brachial arteries.

Distal peripheral TIVS were used successfully in three vessels of two patients (3%): a 16 gauge angiocatheter in a posterior tibial (PT) artery and two 8 Fr. Argyle shunts in the radial and ulnar arteries of a young woman who had successful replantation of her forearm.

Truncal/Visceral Vascular Injuries

Six patients (9%) had TIVS placed in 6 (6%) truncal or visceral arteries: 2 (33%) superior mesenteric arteries (SMA), 3 (50%) external iliac arteries (EIA), and 1 (17%) subclavian artery. All the arteries were shunted at the initial operation for damage control purposes and had an average "dwell" time of 21.8 hours. Three patients (50%) died after their reoperation: one patient succumbed to overwhelming sepsis after ligation of his external iliac vein (EIV), primary repair of a shunted EIA, and damage control management of multiple colonic injuries; another patient was pronounced brain dead after blunt trauma caused a thoracoscapular dissociation requiring amputation; and the last patient's family withdrew care after thrombosis of a TIVS in his SMA after a GSW to the

Table 4 Anatomic Distribution of Temporary Intravascular Shunts

Type of Shunt	n (%)				
	SFA (n = 21)	POA (n = 21)	POV (n = 15)	SFV (n = 12)	BrA (n = 10)
14 Fr. Argyle	9 (39%; all males)	7 (33%; 6 males, 1 female)	7 (47%; all males)	5 (42%; all males)	
12 Fr. Argyle	5 (22%; 4 males, 1 female)	2 (10%; all females)	3 (20%; 2 males, 1 female)		3 (30%; all males)
10 Fr. Argyle		6 (29%; 5 males, 1 female)			3 (30%; all males)
24 Fr. CT				2 (17%; all males)	
20 Fr. CT			2 (13%; all males)	1 (8%; female)	
18 Fr. CT			1 (7%; female)	1 (8%; male)	
16 Fr. CT			1 (7%; female)	2 (17%; all males)	
9 Fr. P-I	7 (30%; all males)	6 (29%; 1 male, 5 females)	1 (7%; male)		3 (30%; all males)
5 Fr. ped FT					1 (30%; male child)

Argyle indicates Argyle shunt; BrA, brachial artery; CT, chest tube; FT, feeding tube; ped, pediatric; POA, popliteal artery; POV, popliteal vein; P-I, Pruitt-Inahara shunt; SFA, superficial femoral artery; SFV, superficial femoral vein.

abdomen. Of the three survivors (50%) in this group, only one experienced end-organ salvage (33%).

Fasciotomy

Fifty-three patients (80%) received prophylactic fasciotomies for extremity compartment syndrome, and three additional patients (5%) underwent this procedure for confirmed compartment syndrome at their reoperation for definitive revascularization. Five patients (8%) who had normal compartment pressures and another five patients (8%) who had significant tissue loss with essentially "open" compartments did not have fasciotomies performed. None developed subsequent compartment syndrome.

"Dwell" Time

Thirty-five patients (53%) had the TIVS removed during the initial operation after orthopedic fixation was accomplished and/or other injuries were managed appropriately. Definitive vascular repairs were performed in these cases. Thirty-one patients (47%), however, left the OR with one or more TIVS (35 arterial, 13 venous) in place. In this group, the average "dwell" time was 23.5 ± 15.7 hours (2–71 hours). The longest period of time an arterial and venous shunt remained patent was 71 hours and 35 hours, respectively. No shunt dislodged during orthopedic stabilization or during transport.

Table 5 **Combined Popliteal Artery and Vein Temporary Intravascular Shunting**

	Mean ± SEM
BD	10.5 ± 8.1
ISS	12 ± 5.4
PRBCs (units)	13 ± 1.9
Dwell time (hrs)	21 ± 1.9
Left OR with TIVS	4 (29%)
Associated fracture or dislocation	13 (93%)
Amputation rate	4 (29%)
Overall survival	13 (93%)*

* One death secondary to loss of airway on postoperative day 25.

BD indicates base deficit; ISS, Injury Severity Score; OR, operating room; PRBCs, packed red blood cells; SEM, standard error of mean.

Multiple TIVS

Thirty patients (45%) each had two TIVS utilized, and one patient (2%) had three vessels shunted during the initial operation. The average base deficit for this critically ill population was 12.9 ± 7.9 with an average ISS of 16 ± 9.8 and average packed red blood cell units transfused of 14 ± 8.9. Fourteen (45%) of those patients had TIVS placed in the POA and POV for concomitant injuries (Table 5), and 10 (32%) had them placed for SFA and SFV injuries. Fifteen patients (48%), including one with three TIVS, left the OR with multiple TIVS in place with an average "dwell" time of 24.1 ± 12.9 hours.

Indications for TIVS

The most common indication for the use of TIVS in this series was damage control (44%), followed closely by Gustilo IIIc open fractures (42%). In the damage control group, TIVS were employed in 25 patients (81%) with peripheral vascular injuries and six patients (19%) with truncal vascular trauma. Six patients (9%) had TIVS placed to allow for management of other injuries and further preparation (i.e., harvest of vein) so definitive vascular repair was able to be performed during the first operation. One patient (2%) had successful replantation of her forearm with the assistance of TIVS in her radial and ulnar arteries. When comparing the damage control group to the nondamage control group, the damage control group had a worse base deficit, a higher transfusion requirement, and a higher amputation rate (Table 6).

Patency of TIVS and Secondary Amputation Rate

Among the 35 patients (53%) who were in the ICU with the TIVS in place, three shunts (9%) occluded (all arterial) which initiated an early reoperation. Two of these were 8 Fr. Argyle shunts in the SMA, and one was a 9 Fr. P-I shunt in

Table 6 **Indications for Temporary Intravascular Shunts**

	Damage Control Group			Nondamage Control Group				Total	*p*
	All Damage Control	Extremity	Truncal	All Nondamage Control	Gustilo IIIc Open Fractures	Perfusion During Prep	Limb Replant		
No. patients (%)	31 (47%)	25 (38%)	6 (9%)	35 (53%)	28 (42%)	6 (9%)	1 (2%)	66 (100%)	—
Mean BD	15.2 ± 1.5	15.3 ± 1.7	15.1 ± 2.4	7.2 ± 0.8	6.8 ± 3.5	7.2 ± 9.7	—	10.7 ± 7.8	<0.001
Mean ISS	18 ± 1.7	18 ± 2.0	17 ± 3.1	13 ± 1.3	13 ± 1.6	11 ± 1.8	9	15 ± 1.1	0.016
Mean PRBCs (units)	15.2 ± 2.2	12.6 ± 1.8	26.0 ± 7.3	7.9 ± 0.7	8.0 ± 4.4	10.7 ± 7.7	18	11.8 ± 9.7	0.002
Fasciotomy rate	86%	92%	67%	74%	68%	100%	100%	82%	0.19
Mean "dwell" time (h)	23.5 ± 2.8	23.0 ± 3.2	25.7 ± 6.6	—	—	—	—	23.5 ± 2.8	—
Amputation rate	23%	20%	33%	11%	14%	0%	0%	17%	0.003
Shunt thrombosis rate	10%	4%	33%	0%	0%	0%	0%	5%	0.06
Survival rate	81%	84%	67%	94%	100%	67%	100%	88%	0.09

BD indicates base deficit; ISS, Injury Severity Score; P-I, Pruitt-Inahara; PRBCs, packed red blood cells; Prep, preparation.

Table 7 Patients Who Underwent Secondary Limb Amputations

Patient	Age (yr)/ Sex (M/F)	Mech	Assoc Fractures	ISS	BD	Vessel(s) Shunted	TIVS Used	"Dwell" Time (hr)	PRBCs (units) During Initial Operation	Presumed Reason for Amputation
1	51/F	Crush injury	Yes	9	11.4	POA, POV	14 Fr. Arg, 18 Fr. CT	—	14	Thrombosed graft and sig tissue loss
2	40/M	Crush injury	Yes	9	2.9	BrCA	9 Fr. P-I	8	23	Axillary-radial/ulnar bifurc RSVG thrombosed
3	31/M	MVC	Yes	34	11.0	SCA, BrCA	? Fr. Arg, 9 Fr. P-I	2	28	Unsalvageable with brachial plexus injury & severe fractures
4	23/M	GSW	Yes	9	24.2	CFA, POA	9 Fr. P-I, 9 Fr. P-I	29	40	Necrotic muscle & sig tissue loss
5	54/M	GSW	Yes	9	6.8	POA	9 Fr. P-I	29	16	Osteo of foot
6	56/M	GSW	Yes	10	9.0	BrCA	9 Fr. P-I	11	6	Thrombosed shunt, followed by thrombosed graft & necrotic muscle
7	20/M	GSW	Yes	9	7.6	POA, POV	9 Fr. P-I, 14 Fr. Arg	—	19	Graft infection
8	21/M	GSW	Yes	9	7.2	POA, POV	10 Fr. Arg, 12 Fr. Arg	—	11	Thrombosed graft, followed by necrotic muscle
9	18/F	Ped vs. auto	Yes	22	9.0	POA, POV	10 Fr. Arg, 12 Fr. Arg	—	8	Graft infection
10	45/M	GSW	No	20	16.4	EIA, SFA	16 Fr. CT, 12 Fr. Arg	52	37	Multiple other injuries; shock, relatively delayed shunting

Arg indicates Argyle shunt; Assoc, associated; BD, base deficit; bifurc, bifurcation; BrCA, brachial artery; CT, chest tube; EIA, external iliac artery; F, female; Fr., French; GSW, gunshot wound; ISS, Injury Severity Score; M, male; MVC, motor vehicle collision; Mech, mechanism; osteo, osteomyelitis; Ped vs. auto, pedestrian versus automobile; P-I, Pruitt-Inahara shunt; POA, popliteal artery; POV, popliteal vein; PRBCs, packed red blood cells; RSVG, reversed saphenous vein graft; SFA, superficial femoral artery; sig, significant; SMA, superior mesenteric artery; TIVS, temporary intravascular shunts.

a brachial artery. All three of these patients eventually would have required end-organ resection. One patient, however, with ischemic small bowel, expired on posttrauma day 1 without resection after his family decided to withdraw care. An additional nine patients (14%) required secondary amputations for complications of thrombosed grafts, massive tissue loss, and associated infections. Table 7 lists the patients who underwent secondary amputations, including the patient described above whose TIVS thrombosed in his brachial artery, and the presumed reasons for failed limb salvage.

Vascular Reconstruction

The 66 patients had 119 injured vessels (72 arteries, 47 veins). Five vascular injuries (4%) had TIVS inserted and, on return to the OR, required amputation or end-organ resection secondary to thrombosed shunts (n = 2) or unsalvageable limbs (n = 3). The remaining 114 vascular injuries were repaired with 58 (51%) greater saphenous vein grafts (GSVG), 31 (27%) polytetrafluoroethylene (PTFE) grafts, 14 (12%) primary repairs, and 11 (10%) ligations. One morbidly obese patient with a popliteal artery injury and a dislocated knee initially had her knee stabilized only with a knee immobilizer after placement of a reverse GSVG. The graft disrupted and the subsequent repair was performed with PTFE after placement of an external fixator. Another patient had concomitant injuries to the common femoral and popliteal vessels. TIVS were placed in the two arteries, and the two veins were ligated. On reoperation 29 hours later, all four vessels were reconstructed with PTFE.

Blunt Versus Penetrating Trauma

The overall survival rate was 88% with a limb salvage rate of 74%. Survival and limb salvage rates were comparable in the penetrating and blunt trauma subgroups, even though initial base deficits ($p < 0.001$), "dwell" times, transfusion requirements, and indications differed (Table 8).

Damage Control Truncal Versus Peripheral Injuries

When comparing the damage control truncal injury subgroup to the peripheral injury subgroup, transfusion requirements ($p = 0.006$) and shunt thrombosis rate ($p = 0.03$) were statistically significantly higher in the truncal group, although both thrombosed shunts in this group were SMA shunts (Table 9).

Damage Control and Fractures

Patients in the damage control peripheral vascular injury subgroup were further divided into those with associated extremity fractures (n = 13) and those without fractures (n =

Table 8 **Comparison of Penetrating and Blunt Trauma Patients**

	n (%)		p
	Penetrating (n = 42)	Blunt (n = 24)	
BD	13.3 ± 1.3	6.2 ± 0.8	<0.001
ISS	15.7 ± 1.4	13.9 ± 1.8	0.20
Most common vessel shunted	SFA 19 (45%)	POA 8 (33%)	—
Indication			0.03
Damage control	24 (57%)	7 (29%)	
Gustilo IIIc fracture	14 (33%)	15 (63%)	
Limb perfusion	4 (10%)	2 (8%)	
PRBCs (units)	13.6 ± 1.7	8.9 ± 1.5	0.03
"Dwell" time (hr)	26.1 ± 2.4	14.6 ± 2.5	0.04
Amputation rate	7 (17%)	4 (17%)	1.00
Overall survival	37 (88%)	21 (88%)	0.94

BD indicates base deficit; ISS, Injury Severity Score; POA, popliteal artery; PRBCs, packed red blood cells; SFA, superficial femoral artery.

12). The patients with fractures had a higher amputation rate (38%; $p = 0.02$). Other variables which were statistically significantly different between the two subgroups were base deficit, ISS, transfusion requirements, and incidence of POA injuries (Table 10).

Long-Term Follow-Up

Eight of 66 patients (12%) were able to be contacted for long-term follow-up. Their injuries were to EIV (n = 1), SFA (n = 2), SFV (n = 2), POA (n = 5), POV (n = 2), and brachial artery (n = 1). All patients had successful limb salvage, and the longest time from injury to follow-up was 8 years. Six (75%) patients still have pain in their injured limb, and all eight have some functional deficit. Five (63%) patients have mild edema, and three (38%) use compression stockings, although no patients have ulcers or wounds on their extremities. Two patients (25%) take an 81 mg aspirin daily and only two patients (25%) have returned to work or school. Three patients (38%) required further surgery after their discharge from the hospital: one patient underwent replacement of a rod in his tibia; another, who was 12-years old when he was injured, required lengthening of his injured leg; the last patient, who had concomitant injuries to his SFA, SFV, and femur, and who had PTFE grafts used to repair his injured vessels, subsequently developed infections of his arterial graft and his femoral rod, leading to replacement of both. The SFA was ultimately repaired with reversed GSVG.

Table 9 **Comparison of Damage Control Truncal and Peripheral Vascular Injuries**

	n (%)		p
	Truncal (n = 6)	Peripheral (n = 25)	
Mean BD	15.1 ± 2.4	15.3 ± 1.7	0.49
Mean ISS	17.2 ± 3.1	17.6 ± 2.0	0.46
PRBCs (units)	26 ± 7.28	12.64 ± 1.6	0.006
"Dwell" time (hr)	25.7 ± 6.59	23.0 ± 3.2	0.36
Limb/end-organ resection rate	2 (33%)	5 (20%)	0.48
Shunt thrombosis rate	2 (33%)	1 (4%)	0.03
Overall survival	4 (67%)	21 (84%)	0.33

BD indicates base deficit; ISS, Injury Severity Score; PRBCs, packed red blood cells.

Table 10 **Comparison of Patients With and Without Associated Fractures in Patients Who Left the Operating Room With Their TIVS (i.e., Damage Control Group)**

	n (%)		p
	Associated Fracture	No Associated Fracture	
Mechanism: GSW	7 (54%)	11 (92%)	—
Injuries to POA	8 (62%)	1 (8%)	0.006
Mean BD	11.8 ± 2.5	19.4 ± 1.8	0.015
Mean ISS	13.2 ± 2	22.4 ± 3.2	0.009
PRBCs (units)	14.2 ± 3.3	11.0 ± 1.4	0.20
"Dwell" time (hr)	17.8 ± 3.0	28.6 ± 5.5	0.045
Fasciotomy rate	13 (100%)	10 (83%)	0.125
Amputation rate	5 (38%)	0 (0%)	0.016
Thrombosed grafts	2 (15%)	0 (0%)	0.16
Overall survival	11 (85%)	10 (83%)	0.93

BD indicates base deficit; GSW, gunshot wound; ISS, Injury Severity Score; POA, popliteal artery; PRBCs, packed red blood cells; SFA, superficial femoral artery; TIVS, temporary intravascular shunts.

DISCUSSION

Although TIVS have been used routinely during carotid artery surgery since first reported in 1959,[19] there is less experience with their use in ischemic extremities. In 1919, Sir George Henry Makins published his experience on vascular injuries in World War I and defined the elements which influence gangrene and limb loss, including the severe lack of blood flow because of massive hemorrhage. He described the successful use of paraffin-coated silver tubes as conduits in injured arteries. After approximately 4 days, the tubes filled with laminated clot. They were then removed and the injured vessels were ligated. Makins reported limb salvage by using this method in a small number of injured soldiers. He suggested that gradual thrombosis allowed for weaning from the primary circulation and for collateral branches to supersede.[11]

In 1963, Malan and Tattoni's[1] histologic studies showed that the critical period to prevent irreversible nerve and muscle damage in a setting of acute ischemia is 6 to 8 hours. In 1971, Eger et al.[4] reported their use of TIVS in 1971 in patients with injuries to the subclavian and popliteal arteries. Their indications for TIVS, which still apply today, included the following: multiple severe injuries to a vessel; ischemia for 6 hours or more after injury, independent of tissue damage; arterial injuries in more than one extremity; and replantation of avulsed limbs.

The most recent reviews of TIVS have been in the management of wartime vascular injuries. Several publications have emerged from experience during Operation Iraqi Freedom.[12–14] The use of TIVS has been extended into this austere environment and, in addition to the standard indications listed above, has also allowed perfusion of limbs during transport out of forward settings. In these situations, TIVS often remain in place for only 2 hours to 6 hours, allowing the quick evacuation maneuvers to a higher echelon of care, where definitive revascularization occurs. If secured properly, TIVS rarely dislodge which is confirmed by the military's success in relative turbulent transport of patients away from forward locales.[13,14]

Since Eger's initial report, TIVS have been used successfully in complex vascular injuries of the extremities with skeletal fractures and massive soft tissue destruction to reestablish limb perfusion while preparing for vascular repair or orthopedic stabilization. Additionally, TIVS have been employed in mangled extremities while debridement is performed in adequately perfused limbs which allows for a better assessment of soft tissue viability, and they are an established option to allow for abbreviation of surgery in the damage control setting without limb sacrifice.[10] Also, TIVS have been used to allow time for intraoperative orthopedic and plastic surgery consultations to assess limb salvageability. Indeed, two patients excluded from our study had TIVS placed for the aforementioned reason and eventually underwent amputations. This approach of managing mangled extremities with TIVS and sufficient time for proper evaluation is superior to the hasty revascularization which may end in secondary amputation, with muscle necrosis, secondary infection, and sepsis.[3] Of note the remaining five patients who were excluded from our study underwent emergency department thoracotomies with cross-clamping of their descending thoracic aortas and died from decompensated shock with their TIVS and cross-clamps in place. We chose to exclude all seven of these patients as their outcomes were not related to the shunting procedure.

Over the years, many different types of shunts have been used for temporary revascularization. Shunts may be classified as "in-line" or "looped" shunts. The most common TIVS used in our institution were the "in-line" Argyle shunts and small caliber CTs (Fig. 2). These are technically very simple and quick to place and, therefore, very practical in damage control settings. CTs, most commonly used in veins in this series, were used when 14 Fr. Argyle shunts were not large enough to accommodate the vessel. Other "in-line" shunts available are the Javid shunt (C.R. Bard, Billerica, MA) and the Sundt shunt (Integra Neurosciences, Plainsboro, NJ). Javid shunts have cone-shaped bulbs on the ends, and special forceps or Rumel tourniquets can be used to secure the shunt to the vessel (Fig. 3). All "in-line" shunts can be secured in place with soft rubber vessel loops or heavy silk ties. P-I and some Sundt shunts exist in the "looped" configuration[13] (Fig. 4). P-I shunts have intraluminal occluding balloons at the ends to support them in the vessel with ports at the center for balloon inflation, angiography, and infusion of heparin or a vasodilator (Fig. 5). In addition, a variety of other conduits have been used as shunts, such as polyvinylchloride endotracheal suction catheters, sterile nasogastric tubes, simple pol-

Fig. 2. *An Argyle shunt and a chest tube in the popliteal artery and vein in a patient with a near amputation.*

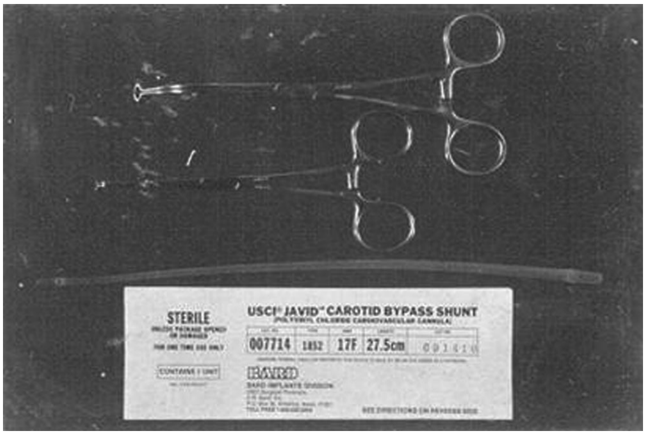

Fig. 3. *Javid shunts with cone-shaped bulbs on the ends.*

Fig. 4. *The "looped" Pruitt-Inahara shunt in a popliteal artery. The popliteal vein has been repaired with PTFE graft.*

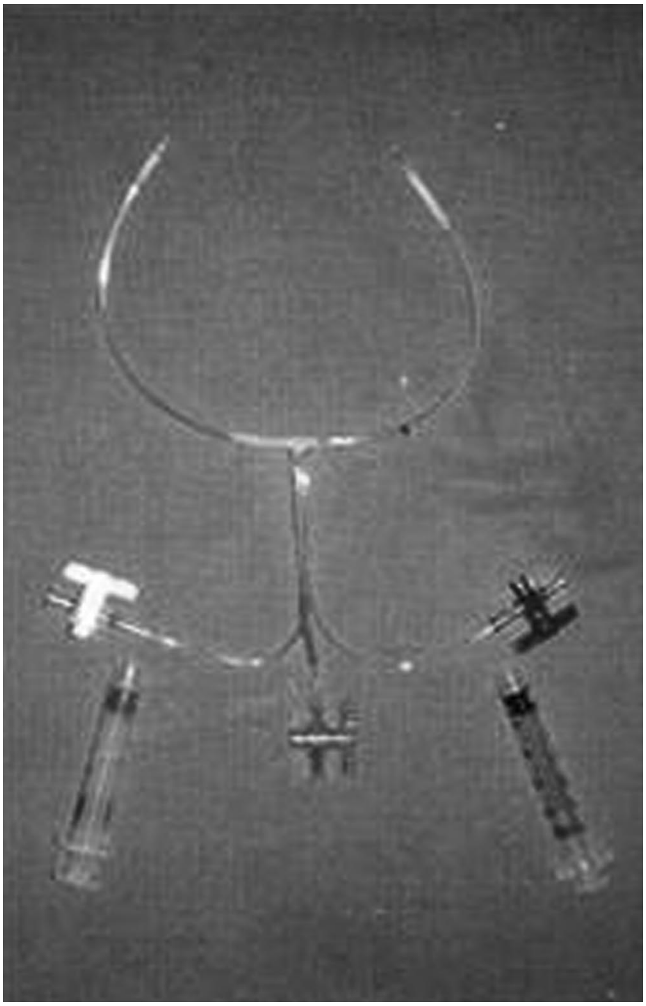

Fig. 5. *Pruitt-Inahara shunt with intraluminal occluding balloons at the ends and ports at the center for balloon inflation, angiography, and infusion of heparin or a vasodilator.*

yethylene intravenous and extension tubes, and pediatric feeding tubes.[3,6,13,15,20] Along with a 5 Fr. pediatric feeding tube in a 2-year old's brachial artery, a 16 gauge angiocatheter was used successfully in a young male's PT artery in this series.

In our experience, penetrating injuries (64%) required TIVS more than blunt (36%). Some suggest blunt vascular trauma possesses a higher amputation rate because of the high-energy transfer that causes extensive tissue destruction.[6,7] However, in this series, even though the patients with penetrating trauma had a worse initial base deficit, the amputation rates and overall survival were comparable between the two groups. It may be that although patients with blunt trauma have more local tissue damage, this may be offset by the penetrating trauma patients' worse physiology leading to equivalent outcomes.

We also noted that patients with Gustilo IIIc fractures who require TIVS in damage control situations have a higher amputation rate than those patients with peripheral vascular injuries without associated fractures.[3] In our series, even though the damage control nonfracture subgroup had worse base deficits (19.4 ± 1.8 vs. 11.8 ± 2.5) and higher ISS (22 ± 3.2 vs. 13 ± 2), they had a lower amputation rate (0% vs. 38%), indicating that Gustilo IIIc fractures carry a significant morbidity, which is likely because of the often associated soft tissue injuries and may also be reflective of the higher percentage of POA injuries (62% vs. 8%; $p = 0.006$) in the fracture subgroup.

The primary purpose of TIVS is to preserve tissue viability to allow for limb salvage. Among the most morbid injury complexes are combined POA and POV injuries. Historically, this carries an extremity amputation rate of 27% after blunt trauma and 9% after penetrating trauma.[2] Unfortunately in this series, combined shunting of the POA and POV did not improve upon this rate. Indeed, combined POA and POV injuries had an amputation rate of 40% (2 of 5) for blunt mechanism of injury and 22% (2 of 9) for penetrating trauma even with shunting. One patient required an amputation 2 days after the initial procedure for a thrombosed reversed saphenous vein (RSV) and PTFE grafts in the artery and vein, respectively. Another patient thrombosed a popliteal-PT RSV graft and underwent an above-the-knee amputation. The last two patients requiring amputations suffered PTFE and RSV graft infections, with the latter enduring a "graft blowout." Therefore, while shunting allows initial salvage in this morbid injury complex, limb salvage does not seem to be improved.

Trauma patients with injuries in multiple body cavities can suffer a delay in recognition and management of extremity vascular injuries. This delay in reestablishing vascular continuity has a significant effect not only on the chance of limb salvage but also on the final functional result.[3] Other factors that may lead to amputation include: associated soft tissue defects with or without concomitant orthopedic injuries, a prolonged period of ischemia, and inadequate soft tissue debridement at the time of vascular repair. Furthermore, hypotension can decrease the 6 hour to 8 hour critical period for reperfusion.[3]

These principles are exemplified by patient 10 (Table 7) in our series who suffered multiple GSW to the lower extremity and abdomen and required a "damage control" laparotomy with control of injuries to his colon, small bowel, EIA, and SFA, as well as ligation of his EIV with calf fasciotomies. Even though arterial continuity was established within 6 hours of injury, the patient's profound hypothermia, acidosis, and coagulopathy impaired reperfusion and warranted an eventual above-the-knee amputation.

Systemic anticoagulation is generally not necessary, especially in trauma patients who undergo TIVS for damage control purposes who are inherently coagulopathic.[10] Adequate sizing of the shunts to the injured vessels can prevent thrombosis. The longest reported time a TIVS remained patent in vivo without systemic anticoagulation was 10 days in an axillary artery.[21] In our experience, arterial shunts have remained patent for at least 71 hours and venous shunts for 35 hours. Indeed, the only shunt thromboses in this series occurred in small vessels (two SMA, one distal brachial artery), and no shunt thromboses occurred in proximal vessels even without anticoagulation.

The limitations of this study are apparent and include a lack of information on postoperative management of these patients. Data such as administration of postoperative dextran, heparin, aspirin, or low-molecular weight heparin after definitive reconstruction were difficult to find. Information regarding the timing of shunting in relation to the injury and presentation times was also difficult to acquire. In addition, the use of TIVS is not protocol-driven in our institution, and therefore there is sometimes either a delay or haste involved in using this modality, and this may cloud some of the outcomes. With increasing experience and possible development of a protocol, limb salvage may improve. A protocol would also permit collection of prospective data, in contrast to the retrospective data analyzed in this study. A final weakness would be the paucity of long-term patient follow-up.

Based on our data as well as recent wartime literature, we support the liberal use of TIVS in trauma patients and feel that they are an important tool in an acute care surgeon's armamentarium. These devices are easy to use, ubiquitous in the OR, have excellent patency rates, and are difficult to dislodge. For successful outcomes, attempts should be made to utilize the largest caliber shunt possible, and anticoagulation is generally not necessary in these patients who are inherently coagulopathic. In our experience, we utilized a variety of shunt types and sizes, some made for the purpose of vascular shunting, and others improvised. Regardless of the type and size, all of the TIVS worked equally well with a mean "dwell" time of 24 hours without systemic anticoagulation, as long as they were adequately sized and the vessels in which they were placed were not very small. This damage control modality should be used in patients with unfavorable physiology who are best served by on-going resuscitation in an ICU rather than a lengthy vascular procedure. Other populations in which this modality has proven useful include patients with Gustilo IIIc fractures in need of orthopedic stabilization and aggressive soft tissue debridement; those with complex vascular or associated torso injuries who require reperfusion while preparing for revascularization; and those who require limb replantation.

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DISCUSSION

Dr. Donald H. Jenkins (Lackland, Texas): Thank you, Dr. Subramanian for your insightful presentation and for providing me a copy of your manuscript well in advance of the meeting. The opportunity to see all of the charts was helpful.

In this paper Dr. Subramanian and her colleagues describe their ten-year experience with the use of temporary intravascular shunts in trauma patients. Interestingly, nearly 50 percent of these patients had multiple vessels shunted and nearly 50 percent of these shunts were placed under damage control circumstances. Ten percent of these patients were excluded from evaluation due to death or early primary amputation on the day of injury.

At the end of the analysis the shunt thrombosis rate was 5 percent, the amputation rate almost 20 percent, limb salvage and live patients at 73 percent, and overall survival, 88 percent.

There is no information presented on the timing of the shunt placement relative to the time of injury or diagnosis of vascular injury. Likewise, there is little information presented to link the timing or performance of fasciotomes to these eventual outcomes.

I would like to focus my remarks and questions on a few key areas of this work and the analysis provided. First, I'm unsure as to the reason to exclude the patients who died or underwent primary amputation on the day of injury despite attempts at shunting. Could these represent shunt failures or delayed shunt placement that would significantly change the apparent success associated with shunt use?

Next I would like to address the lack of comparison group. That group of patients with vascular injury undergoing primary repair, ligation or amputation without shunt. Understanding how the Emory group approaches patients with vascular injury in toto is important to interpret the true success and limitation of shunts in this severely-injured patient population.

What are the mortality rates and limb salvage rates in damage control patients undergoing primary vascular repair without shunt? And what is the essential role for shunting?

In your manuscript I counted 12 of 35 intravascular shunts still in place after the first operation which resulted in either thrombosis or delayed amputation. Can you identify the key factors that separate out this failure group from the successful shunt group? Is the contribution to this failure related to shunt size, vessel injured, number of vessels shunted, associated injury patterns, use and/or timing of fasciotomy or the timing of the shunt placement?

Finally, I would like to highlight the significant use of shunts in venous injuries in this patient population.

I would appreciate a straight-forward answer based on the experience presented here as to the circumstances under which venous shuts should or should not be used. Inquiring trauma surgeons everywhere want to know.

I hope that straight-forward answer will include anatomical site, physiologic parameters, the role of arterial shunting, timing of that shunt placement, and the role of the fasciotomy.

This paper is well written and contains an incomparable series of severely-injured patients requiring vascular shunting, including multiple shunted vessel patients and venous injury shunt patients, and provides an important benchmark in civilian trauma, mainly the mortality limb salvage rates in vascular shunt patients, especially those requiring damage control.

I thank the authors for their outstanding contribution to the science and the care of these severely-injured patients and to the association for the privilege to discuss this paper.

Dr. Juan A. Asensio (Miami, Florida): Personally, I think that shunts in the femoral arteries have the best survival followed by brachials and then popliteals. I just have one, very simple question. Did you use papaverine prior to the insertion of the shunt?

As we know, significant distal vessel spasm is present, whether you pass or do not pass Fogarty Catheters, which we always do. In those shunted patients, did you use an infusion of low molecular weight dextran post operatively.

I think this is a significant paper. I'd like to congratulate the authors for their contribution.

Dr. C. William Schwab (Philadelphia, Pennsylvania): It's an interesting paper. I'd ask just a few things and then maybe if you could extrapolate your series to some futuristic things.

First and foremost, did you look at the length of the shunt that was used? If you go back to basic physics, flow is related to the radius to the fourth power inversely related to the length squared. So length actually decreases flow. Was there any correlation attempted between shunt length and potency? Should we have avoided longer coiled shunts and use the shortest possible straight shunt?

In those shunts that you would use in the future, if it was especially long, would you recommend a heparin bonded shunt to enhance flow or decrease resistance?

And, second, are you better off using a heparin bonded shunt on the venous side rather than a non heparin bonded or an exposed plastic shunt like a chest tube?

Perhaps, we are substituting larger diameter (chest tube) size for something that technically is available to us (heparin bonded)? Smaller diameter may decrease initimal injury. Please speculate.

Dr. Danny Jazarevic (Stuart, Florida): Unfortunately, Dr. Jenkins and a few other people here, including me, have a lot of experience with those shunts. Our series in the military, 70 percent of the upper extremity because brachial arteries are so often injured.

Maybe that has changed a little bit. But, the thing is that we're trying to cut argyle shunts. Can't do it because them things are very hard and very brittle so you can't cut it so you will have to have a shunt that is sort of short right away because it's hard to put in a vessel once it's sort of –

The question I have is wouldn't you consider at this point doing fasciotomy in everybody because you have two series that are all damage controls.

One is damage control surgery systemically. The other is damage control surgery locally. Those that you say, no damage control, also damage controls only local, i.e., they have, you know, fracture of this or that.

And so I think you should, from this you may want to extrapolate to say, well, we should do a fasciotomy probably on everybody. Most of these that's a failure is because the blood pressure goes down on the patient in systemic dire straits. But that's what happens.

Dr. Steven R. Shackford (Burlington, Vermont): Just one additional comment in follow up to what Bill said. I think that you should look also at hematocrit because viscosity is going to impact resistance more than the length.

Dr. Anuradha Subramanian (Atlanta, Georgia): I'd like to thank Dr. Jenkins and the audience for the very interesting and provocative questions.

To answer Dr. Jenkins' first question, we had five immediate deaths that were related to other injuries. And two primary amputations were done after a multidisciplinary evaluation allowed for a decision to perform a primary amputation.

While these patients illustrate the value of shunting as a damage control adjunct, further analysis of their outcomes did not seem relevant as it was not related to the shunting procedure.

The second question addresses the lack of comparison group. At Grady we are very aggressive with the application of all damage control principles and this would include the use of shunts.

Over the last ten years we had over 20,000 trauma admissions and we took care of 786 patients with vascular injuries. I do know that our amputation rate in non-damage control situations is low; however, I do not have a specific number.

In regards to the third question, there were ten amputations and two small bowel resections in patients for whom damage control shunts were placed. In three of these cases the thrombosed shunts played a role. There were two eight French Argyle shunts in superior mesenteric arteries as well as one nine French Pruitt-Inahara shunt in a distal brachial artery. The most successful shunts were of larger caliber so I believe that both shunt size and vessel shunted played a role in the poor outcome.

Of note, Dr. Feliciano in his presidential address presented one successful SMA shunt that was performed several months ago. One difference in the management of this patient was heparinization. It may be that systemic anticoagulation, if possible, is beneficial when small caliber shunts are used in critical vessels. The remainder of the amputations were secondary to thrombosed grafts, massive tissue loss, and associated infections.

In answer to the last question on the role of venous shunting, we recognize that venous ligation is an accepted practice for many venous injuries and that venous repair is relatively controversial. We feel that temporary shunting of a venous injury allows for continued resuscitation and gives the surgeon the maximum range of possibilities for definitive management. There is little downside to venous shunting and probably helps the patency of arterial shunts and may avoid the need for immediate fasciotomy in a coagulopathic patient.

And in regard to Dr. Asensio's question regarding papaverine, we do not standardly use papaverine in our patients; however, if an intraoperative arteriogram was performed and there did appear to be some vasospasm, it would be the decision of the attending surgeon whether to vasodilate with some papaverine.

We did not give dextran to patients in whom shunts were placed. However, after definitive vascular repair I know that Dr. Feliciano likes to give three days of dextran but that varies from attending to attending. It's by preference.

Someone was asking about the length of the shunt and about cutting the shunts. We usually do cut the shunts. They do come in various, you know, calibers, sizes, but we usually do cut them and we insert as such.

We actually don't have heparin-bonded shunts, and therefore, we don't use them at Grady. So that, I guess if we get them we would have to look at our data.

Regarding fasciotomies, we have a large amount of prophylactic fasciotomies in our series, about 80 percent. And recently we actually don't do as many prophylactic fasciotomies. We are very religious about checking compartment pressures frequently. If there are those patients who do require massive resuscitation, then we do consider performing prophylactic fasciotomies on those patients. I guess another group would be those patients with Gustilo IIIC fractures, performing prophylactic fasciotomies on them as well.

In regards to the patency of various lengths of shunts—that's actually a very good point. Obviously from our pictures there are various lengths of the shunts that we used and defects of the injured vessels. I can't say for sure the one patient that thrombosed, that required an amputation, if that was a longer length of vessel that was injured. That I'm not sure.

In looking at the hematocrit and blood viscosity—we did not look at patients' hematocrits as an outcome based on the shunts. That was not something that we looked at, but that was a good point, too.