TECHNICAL NOTE

Locked Temporary Vascular Shunt for Wartime Vascular Injuries

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Introduction: To reduce the ischaemia time of injured limbs in wartime, temporary vascular shunts (TVS) are commonly used. However, TVS are stabilized at the ends of the injured vessels using manual suture ties, the risk of dislodgement is high, and tightening manual suture ties is too time consuming.
Technical summary: Locked temporary vascular shunts (LTVS) were designed, and each was composed of a silicone tube with a threaded outer surface and smooth inner surface in addition to two nylon buckle switches. The buckle switches were used to stabilize the silicone tube of the LTVS with respect to the vessel walls. This job was performed with two manual suture ties with the current TVS. The mean bursting pressure value of the veins shunted with the LTVS was 114.3% higher than that of the veins shunted with the TVS (0.045 $\pm$ 0.008 MPa vs. 0.021 $\pm$ 0.012 MPa; $p = .00$). Although the mean shunting time of the LTVS was reduced by 60.4% compared with that of the TVS (138.89 $\pm$ 18.22 seconds vs. 350.48 $\pm$ 52.20 seconds; $p = .00$), there was no significant difference in the patency times between the two types of devices (8.20 $\pm$ 9.01 hour vs. 8.40 $\pm$ 8.85 hour; $p = .98$).
Conclusion: The LTVS, which was designed to treat wartime vascular injuries, might be safer and more efficient than the current TVS.

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INTRODUCTION

The conflicts in Afghanistan and Iraq have witnessed an increase in the incidence of vascular injury compared with previous combat reports.[1—6] To reduce the ischaemia time of injured limbs, temporary vascular shunts (TVS) are commonly used.[7] At the Echelon II facility — Forward Resuscitative Surgical Suite in Iraq, upper extremity vascular injuries not amenable to primary repair were routinely shunted by TVS. Once stabilized, with perfusion restored, patients were medically evacuated (MEDEVACed) for definitive treatment and repair at an Echelon III facility.[8] However, because TVS are stabilized at the ends of the injured vessels using manual suture ties, the risk of dislodgement is high,[9] and tightening manual suture ties is too time consuming for military surgeons at Echelon II facilities, particularly when there are large numbers of casualties waiting for rescue.

To eliminate these two problems an improved TVS, the locked TVS (LTVS) was designed. The LTVS has a threaded outer surface and two nylon buckle switches. The objective was to preliminarily evaluate the safety and efficiency of the LTVS.

Supplementary video related to this article can be found at http://dx.doi.org/10.1016/j.ejvssr.2016.07.003.

The following are the supplementary data related to this article:Video S1In the locked temporary vascular shunt insertion procedure, the shunt was stabilized with two buckle switches.
Video S2In the temporary vascular shunt insertion procedure, the shunt was stabilized with four manual suture ties.

SURGICAL TECHNIQUE

Each LTVS (Lituo, Beijing, China) was composed of a silicone tube with a threaded outer surface and a smooth inner surface, in addition to two nylon buckle switches. The length, inner diameter, and external diameter of the silicone tube were 50.0, 3.0, and 6.0 mm, respectively. The threaded internal surface of each buckle switch matched that of the silicone tube (Fig. 1). The length of each buckle switch was

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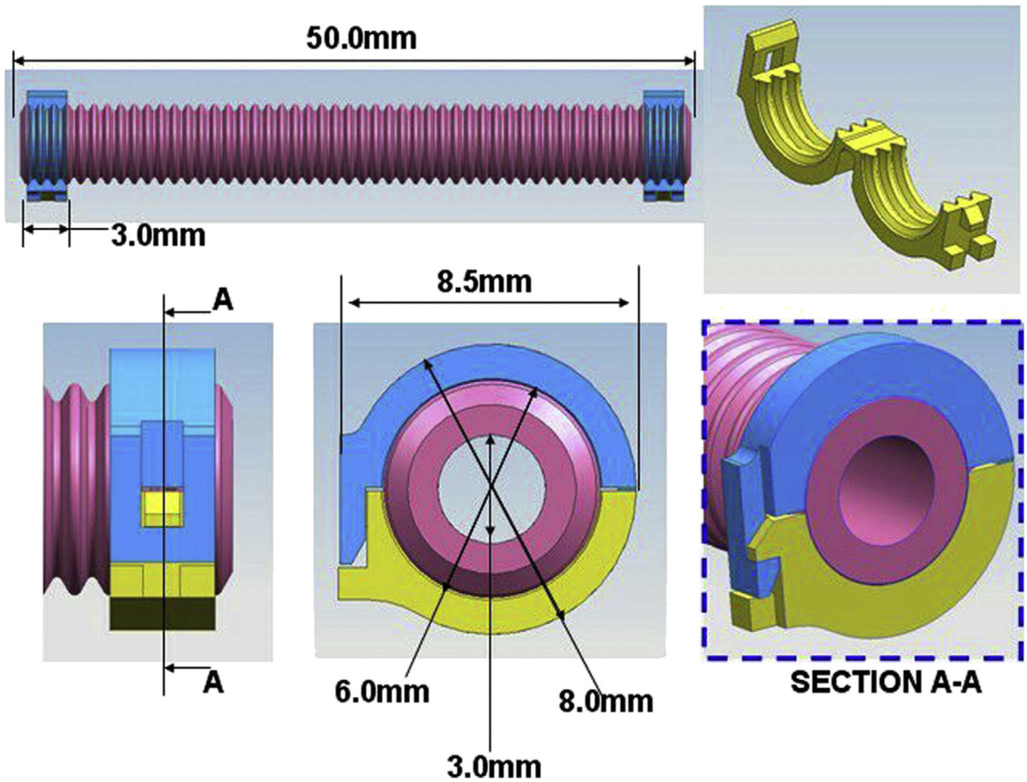

Figure 1. Schematic diagram of the locked temporary vascular shunt.

3.0 mm. Before evaluation, each LTVS was sterilized with 25 kGy gamma irradiation.

Ex vivo *evaluation*

At room temperature, a BD Connecta 394605 three way plastic tube (Becton Dickinson, Helsingborg, Sweden) was connected to a 50 mL syringe (Jierui, Weihai, China) that was fixed to a Graseby 3100 syringe pump (SIMS Graseby, Watford, UK). The other two ends of the three way tube were simultaneously connected to a Junchen piezometer (Huaxia, Zibo, China; range 0—0.1 MPa, accuracy 0.01 MPa) and a sample. A total of 20 samples (10 freshly frozen human brachial veins shunted with 10 LTVS and 10 freshly frozen human brachial veins shunted with 10 TVS) were prepared in parallel and randomly allocated to the two groups for BP measurement. The dimensions of each TVS were 5 mm in outer diameter, 1 mm in thickness, and 50 mm in length. The dimensions of each LTVS were 6 mm in outer diameter, 1.5 mm in thickness, and 50 mm in length. Each LTVS or TVS was stabilized to the proximal end of each vein (approximately 10—15 mm in length with the distal end of each firmly sealed). The freshly frozen human brachial veins were provided by the Bone Tissue Bank of the Chinese PLA General Hospital and were stored in Hank's solution (Sigma-Aldrich, Germany) with 15% dimethyl sulfoxide (Sigma-Aldrich, Munich, Germany) at -80°C before being rapidly resuscitated at 37°C. At each end, the silicone tube of the LTVS or TVS was stabilized using a buckle switch or two manual suture ties. Next, 40 mL saline (0.9% sodium chloride solution) was pumped in at the rate of 199.0 mL/hour. As the saline was continuously pumped, the inner pressure within each sample was simultaneously measured by the piezometer. Bursting represents the time at which disturbance of balance between inner pressure and vessel—shunt friction occurs, regardless of solution leakage or dislodgement. Bursting pressure (BP) means the highest value of inner pressure measured at the time of bursting, and therefore equals the maximum value of friction at the connection site between vessel and shunt. Brachial veins were harvested from donors registered at Bone Tissue Bank of the Chinese PLA General Hospital. All donors signed organ donation consent, and the ethics committee of the Chinese PLA General Hospital (Beijing, China) approved this study. The mean BP of the veins shunted with the LTVS was 114.3% higher than that of the veins shunted with the TVS (one-sample *t* tests [SPSS 13.0; IBM, Armonk, NY, USA], $p = .00$; Table 1).

In vivo *evaluation*

The *in vivo* evaluation was conducted under a protocol approved by the Institutional Animal Care and Use Committee of the Chinese PLA General Hospital. Five healthy adult hybridized dogs weighing 12.10 ± 4.79 kg provided by the Keyu Aquaculture Center (Beijing, China) under certificate No. SCXK 2007-0003 were used in the study, and each was used as its own control. The bilateral femoral arteries were randomly selected for shunting with an LTVS or a TVS (the inner diameters of the two shunts in each dog were the same). Before surgery, the dogs received intramuscular morphine and atropine as pre-anaesthesia and intravenous

Table 1. Comparison of the *ex vivo* bursting pressure (BP) of the locked temporary vascular shunt (LTVS) and the temporary vascular shunt (TVS).

LTVS		TVS	
Vein no.[a]	BP (MPa)	Vein no.[a]	BP (MPa)
15	0.055	1	0.018
13	0.042	2	0.023
8	0.039	6	0.015
16	0.038	7	0.018
20	0.030	11	0.033
9	0.050	14	0.038
19	0.047	10	0.007
3	0.054	5	0.039
4	0.052	17	0.005
12	0.039	18	0.018
Mean	0.045		0.021
SD	0.008		0.012
p-value (two sided)	0.00		
Increase in BP with LTVS vs. TVS (%)		(0.045 − 0.021)/0.021 × 100% = 114.29%	

Note.
[a] Based on donating order.

Table 2. Comparison of the shunting time (ST) between the locked temporary vascular shunt (LTVS) and the temporary vascular shunt (TVS).

Dog no.	ST (s)	
	LTVS	TVS
1	114.43	288.41
2	132.00	355.00
3	138.00	307.00
4	146.00	405.00
5	164.00	397.00
Mean	138.89	350.48
SD	18.22	52.20
p-value (two sided)	0.00	
Reduction in ST with LTVS vs. TVS (%)	(350.48 − 138.89)/350.48 × 100% = 60.37%	

thiopental and isoflurane/oxygen as general anaesthesia. An 8 cm incision was made in each groin to expose the femoral arteries while avoiding injury to the femoral vein and nerve. Subsequently, 2% lidocaine was gently irrigated into the artery for 30 seconds to minimize vasospasm. A bulldog clamp was placed 4 cm distal to the inguinal ligament to occlude the femoral artery. A second bulldog clamp was placed approximately 6 cm distal to the first clamp. A femoral artery defect (2 cm) was created at the centre point between the two clamps. After irrigation with 0.9% sodium chloride solution, one end of the LTVS or TVS (5 cm in length) was inserted into the distal end of the injured artery and stabilized, and the other end of the shunt was then inserted into the proximal end of the artery and stabilized. For each dog, one LTVS was stabilized with two buckle switches, and one TVS was stabilized with four manual suture ties (Fig. 2).

After stabilization, the blood flow was immediately restored by releasing the two clamps. The shunting time (ST) was defined as the time from shunt insertion to restoration of blood flow. Subsequently, the deep tissue and subcutaneous tissue were closed using 4-0 nylon monofilament suture, and the skin was closed using 2-0 nylon sutures in a simple interrupted pattern. At 1, 2, 3, 6, 12, 24, and 48 hours post-operatively, the blood flow of the shunted arteries was monitored using a portable MyLab 25 Gold system (Esaote SpA, Genoa, Italy), and the patency time (PT) (i.e., the time from shunting to re-occlusion) of each shunted artery was recorded. Each dog was allowed to bear their full weight and received 400,000 U penicillin intramuscularly following surgery. No anticoagulants were given. The mean ST of the LTVS was 60.4% less than the TVS (paired *t* tests, $p = .00$) and there was no significant difference in the PT between the LTVS and TVS groups (paired *t* tests, $p = .98$) (Tables 2 and 3). No shunt dislodgment was seen in either group at 48 hours post-operatively.

DISCUSSION

In a peaceful environment, owing to the provision of adequate staff and time for the rescue of wounded personnel, the speed of shunting and stability of the fixed shunt are not of great concern, but it differs in the battlefield environment. In the battlefield environment, routine combat operations remote from local medical facilities, limited medical resources in an austere environment, and the need for further MEDEVACing of casualties to the next level of care contribute to the delay in emergency treatment after injury.[9] In this situation, being pushed for time,

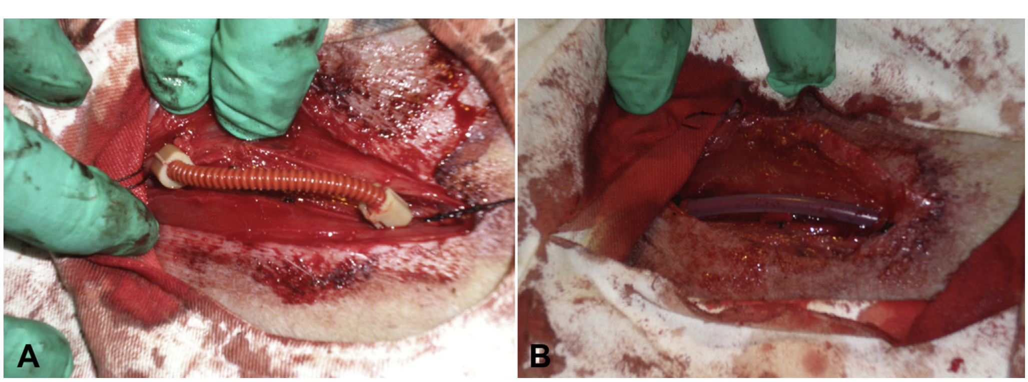

Figure 2. Injured arteries shunted using (A) a locked temporary vascular shunt (LTVS) or (B) a temporary vascular shunt.

Table 3. Comparison of the patency time (PT) between the locked temporary vascular shunt (LTVS) and the temporary vascular shunt (TVS).

Dog no.	PT (h)	
	LTVS	TVS
1	2	3
2	3	3
3	6	6
4[a]	6	6
5	24	24
Mean	8.20	8.40
SD	9.01	8.85
p-value (two sided)	0.98	

Note.
[a] Dead at 12 h post-operatively.

surgeons at an Echelon II facility are required to complete vascular shunting surgery as quickly as possible. Therefore, if the shunts are fixed with suture ties, time constraints will most likely reduce the quality of the ties, and increase the risk of dislodgement. Also, owing to the relative scarcity of ambulance personnel, observation of the shunted vessels may be neglected during evacuation. If dislodgement occurs and is not noted quickly, the consequences may be very serious. In this study, a new LTVS was designed to reduce the stabilization time and risk of dislodgment associated with the currently used TVS. The mean BP in the LTVS group was significantly higher than that in the TVS group. This difference might be attributable to the fact that the contact area between the LTVS threaded outer surface and the vessel wall was increased; the ST was decreased by 60.4% with the LTVS compared with the TVS. This decrease was because it is much faster and simpler to close buckle switches than to tighten manual ties.

Several key points related to the application of the LTVS should also be noted. First, like the TVS, the LTVS has various important characteristics, including a smooth inside wall and calibre matching the TVS, and being sterile, non-toxic, and simple to operate. Second, because the silicone tube and the two nylon switches have a certain degree of toughness, surgeons must be gentle to prevent further deterioration of the vascular injury. Third, when definitive repair is performed, damaged blood vessels should be removed completely. Finally, before being used in real life situations, LTVS should be improved in four aspects: first, because calibres of human limb vessels vary in different anatomical planes, the diameters of LTVS should be variable; second, the outer characteristics of LTVS, such as the shape of entrance and exit, and the thickness and elasticity of the shunt, should be optimally designed to minimize the disturbance of the blood flow; third, the chemical composition of LTVS should be optimized in order to minimize the risk of cytotoxicity or carcinogenicity after implantation; and fourth, some dedicated surgical instruments, such as vascular dilators, clamper for shunts and buckles, should be designed to further simplify shunt insertion.

CONCLUSION

In conclusion, the LTVS might be useful for treating wartime extremity vascular injuries with greater safety and efficiency. Further research is required before this device can be used in real life situations.

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CONFLICT OF INTEREST

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