Original research

A critical appraisal of impact of compounding factors in limb salvage decision making in combat extremity vascular trauma

Amila S Ratnayake,[1] M Bala,[2] C J Fox,[3] A U Jayatilleke,[4] S P B Thalgaspitiya,[5] T J Worlton [6]

[1]Department of General Surgery, Army Hospital Colombo, Colombo, Sri Lanka
[2]General Surgery and Trauma Unit, Hadassah - Hebrew University Medical Center, Jerusalem, Israel
[3]Vascular Surgery, Denver Health Medical Center, Denver, Colorado, USA
[4]Postgraduate Institute of Medicine, University of Colombo, Colombo, Western, Sri Lanka
[5]Faculty of Medicine and Allied Sciences, Rajarata University of Sri Lanka, Mihintale, Sri Lanka
[6]Department of Surgery, Uniformed Services University of the Health Sciences, Bethesda, Maryland, USA

Correspondence to
Dr T J Worlton, General Surgery, Uniformed Services University of the Health Sciences, Bethesda, Maryland, USA; taworlto@yahoo.com

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ABSTRACT

Objective For more than half a century, surgeons who managed vascular injuries were guided by a 6-hour maximum ischaemic time dogma in their decision to proceed with vascular reconstruction or not. Contemporary large animal survival model experiments aimed at redefining the critical ischaemic time threshold concluded this to be less than 5 hours. Our clinical experience from recent combat vascular trauma contradicts this dogma with limb salvage following vascular reconstruction with an average ischaemic time of 6 hours.

Methods During an 8-month period of the Sri Lankan Civil War, all patients with penetrating extremity vascular injuries were prospectively recorded by a single surgeon and retrospectively analysed. A total of 76 arterial injuries was analysed for demography, injury anatomy and physiology, treatment and outcomes. Subsequent statistical analysis was performed to evaluate the impact of independent variables to include; injury anatomy, concomitant venous, skeletal trauma, shock at presentation and time delay from injury to reconstruction.

Results In this study, the 76 extremity arterial injuries had a median ischaemic time of 290 (IQR 225–375) min. Segmental arterial injury (p=0.02), skeletal trauma (p=0.05) and fasciotomy (p=0.03) were found to have a stronger correlation to subsequent amputation than ischaemic time.

Conclusions Multiple factors affect limb viability following compromised distal circulation and our data show a trend towards various subsets of limbs that are more vulnerable due to inherent or acquired paucity of collateral circulation. Early identification and prioritisation of these limbs could achieve functional limb salvage if recognised. Further prospective research should look into the clinical, biochemical and morphological markers to facilitate selection and prioritisation of limb revascularisation.

INTRODUCTION

For more than half a century, a 6-hour ischaemic time limit has guided surgeons in their decision to proceed with vascular reconstruction.[1] Contemporary large animal survival model experiments aimed at redefining the critical ischaemic time threshold concluded this to be less than 5 hours.[2 3] The compounding effect of haemorrhagic shock shortened this to less than 3 hours.[4] Extremity vascular injury with resultant haemorrhagic shock results in ischaemia to distal compartmental muscles with ensuing necrosis in a time-dependent manner. This ischaemic sequelae is circumvented by expeditiously re-establishing distal circulation by vascular reconstruction. The above-mentioned large animal survival models as well as recent research by Alarhayem *et al* correctly emphasised the urgency of restoration of distal circulation by stating '*optimal limb salvage is achieved when revascularisation of lower extremity arterial injury occurs within 1 hour of injury*'.[5]

Sri Lanka suffered from 26 years of civil war and terrorism. The front line was fast moving, in harsh terrain with changing weather patterns which made rotary wing air evacuation challenging. High velocity rifles and artillery inflicted a heavy number of injuries. Combat casualty care was organised into four levels. Up to the second level of care, patients moved exclusively via ground medical evacuation, while levels 3 and 4 had aeromedical evacuation capability. Patients with extremity vascular injuries were prioritised by an evacuation protocol which was established during the study period.[6] The second level of care had the facilities to perform damage control surgery and transfuse non-type matched blood.

Previous research attempts to delineate predictors of poor outcome in extremity vascular trauma did not codify the cases as primary or delayed amputation and did not have the granular data to comment on amputation decisions. These parameters have significant impact as a portion of amputations result due to unsalvageable wound profile (primary amputation) or septic sequelae (secondary amputation) rather than ischaemia. Few did not consider time as an impact factor on outcome.[5 7 8] This paper adds to the body of literature a highly granular data set with meticulous single surgeon recording of combat extremity vascular injury case profiles to

Key messages

- ⇒ Combat trauma in low-income and-middle-income countries can experience prolonged evacuation times leading to ischaemia in vascular injuries.
- ⇒ The authors present data from a cohort of patients with median ischaemia time of 290 minutes.
- ⇒ In this cohort, segmental arterial injury, skeletal trauma and fasciotomy were significantly correlated with amputation.

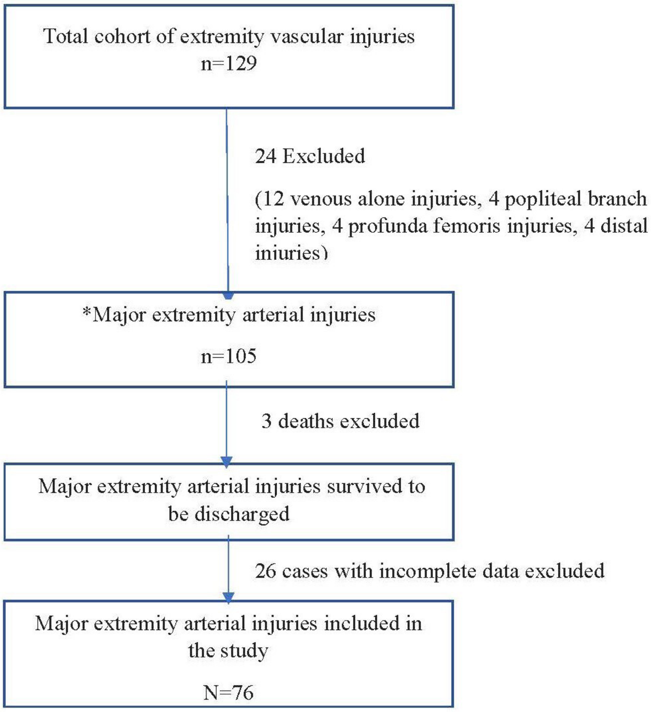

Figure 1 Inclusion criteria. *excluding arterial branches and arteries distal to the popliteal trifurcation and brachial artery bifurcation.

substantiate surrogate markers other than time as crucial factors in limb salvage outcomes.[9]

METHODS

During the last phase of the Sri Lankan Civil War, from November 2008 to June 2009, a total of 5821 combat-related casualties were treated at Military Base Hospital (MBH). Of them, 105 were extremity arterial injuries (1.8%, 105/5821). Twenty-six limbs with inadequate ischaemic time data and three deaths were excluded from the study and therefore 76 arterial injuries were analysed (Figure 1). The analysis included descriptive statistics such as the mechanism of injury, ischaemic time, surgical repair and outcomes. Comparative analysis of delayed reconstruction (>6 hours) versus early repair (≤6 hours) was done to assess statistically significant differences in early outcomes, particularly limb salvage versus amputation.

All the numerical variables were assessed for their distribution. Since none of them were distributed normally, median and IQRs were used to report the numerical variables. Mann-Whitney U test was used to compare means and the χ^2 test and Fisher's exact test were used to assess the associations between categorical variables. Statistical significance was set at p=0.05.

In this study, we retrospectively extracted data from a trauma registry maintained at Army Hospital, Colombo. We did not extract any identifiable personal data. Therefore, this study was exempt from requiring approval by the Ethics Review Committee of Sri Lanka. The authors obtained approval from the Commanding Officer of Army Hospital, Colombo to access the de-identified data.

RESULTS

In total, 76 patients with arterial injuries in the lower limbs were included in this study of which 9 were ultimately amputated. Twenty-two of these 76 patients (29%) had a documented ischaemic time of more than 6 hours. The majority of patients had an ischaemic time of 3 hours to 6 hours (62%, 47/76). There was a median ischaemic time of 290 (IQR 225–375) min.

Table 1 Comparison of injury profiles

Injury profile	Amputation (%) n=9	Salvaged (%) n=67	P value
Popliteal anatomy	5 (55.5%)	18 (27.0%)	0.12*
Segmental arterial injury	9 (100.0%)	39 (58.0%)	0.02*
Concomitant venous injury	7 (77.8%)	28 (42.0%)	0.07*
Skeletal trauma	5 (55.5%)	15 (22.4%)	0.05*
Tachycardic/ hypotensive (<90 mm Hg)	1 (11.1%)	3 (4.5%)	†
Fasciotomy	8 (88.9%)	30 (45.5%)	0.03*
Median ischaemic time (IQR) min	270(232-380) min	295(225-375) min	0.88‡

*Fisher's exact test.
†Inadequate data.
‡Mann-Whitney U test.

Table 1 shows the analysis of multiple factors as they relate to limb salvage in arterial injury. Notably, the median ischaemic time was nearly equivalent between the amputation versus salvage groups (p=0.88). However, several factors did reach statistical significance, namely skeletal trauma, segmental arterial injury and fasciotomy. Table 2 shows the analysis of these same factors broken down by ischaemic time greater than or less than 6 hours. With the exception of skeletal trauma (p=0.06), none of these parameters occurred more frequently in either category thus showing an even distribution of factors across the ischaemic time spectrum. Figures 2–4 graphically present the total injuries broken into 60 min increments as it relates to anatomical distribution, concomitant venous injury and skeletal trauma, respectively.

The anatomical distribution of arterial injuries was as follows: femoral (36.8%, 28/76), popliteal (30 %, 23/76), brachial (22 %, 17/76) and 8 unrecorded arterial injuries. As shown in Figure 2, the majority of amputations were performed due to a popliteal injury (56%, 5/9) despite femoral injuries being more common in total, though this did not reach statistical significance (p=0.12). There was only one amputation in the brachial artery injury group and the rest occurred in the femoral artery cohort.

Table 2 Analysis of injury profile as distributed by ischaemic time

Profile	≤6 hours (54)	>6 hours (22)	P value
Median transfer time (interquartile range) min	255 (205–300)	462 (397.5–643.75)	**<0.001***
Popliteal injuries	17 (31.5%)	6 (27.3%)	0.717†
Repaired with IPVG	44 (81.5%)	19 (86.4%)	0.745‡
Repaired vein injuries	5 (9.3%)	3 (13.6%)	0.684‡
Concomitant venous injury	25 (46.3%)	10 (45.5%)	0.947†
Skeletal trauma	11 (20.4%)	9 (40.9%)	0.065†
Fasciotomy	27 (50.9%)	11 (50.0%)	0.941†
Amputations	7 (13.0%)	2 (9.1%)	1.000‡

*Mann-Whitney U Test.
†χ^2 test.
‡Fisher's exact test.
IPVG, interposition vein graft.

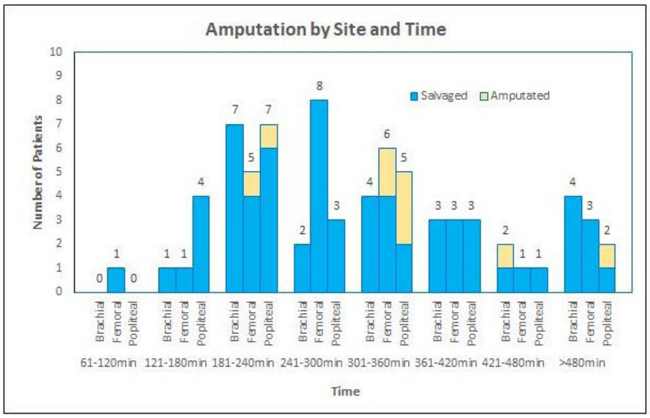

Figure 2 Trends in limb salvage by injury site over time.

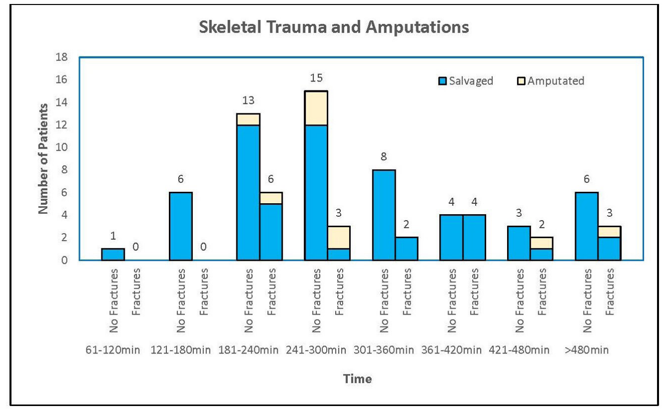

Figure 4 Distribution of arterial injuries with and without skeletal trauma over time.

Concomitant venous injury occurred in 46% (35/76). As shown in Figure 3 and Table 1, seven of the nine total amputations occurred in this group though this did not reach statistical significance (p=0.07). Skeletal trauma occurred in 26% (20/76) of the total arterial injuries. Of the nine amputations, skeletal trauma occurred in five of them reaching statistical significance in its correlation (p=0.05) as shown in Table 1 and Figure 4. The segmental arterial injury group was comprised of complete transections (51%, 39/76) and incomplete transections (12%, 9/76). The remainder of injuries were lateral tears (21%, 16/76), thrombosis (12%, 9/76) and 3 penetrating injuries from fragments. These were predominately repaired with interposition vein graft (83%, 63/76) but five had a saphenous vein patch repair. The remainder of these injuries was treated with embolectomy (2) or ligation (6).

DISCUSSION

In an analysis of 2471 combat-related arterial injuries during World War II there was an average time lag of 12 hours between time of injury and treatment.[10] Therefore, one conclusion was that re-establishing circulation of the limb must be done within the limited period of time after injury. The general and arbitrarily set time limit was 6–8 hours.

Contemporary animal experiments conclude that neuromuscular recovery of an ischaemic extremity is significantly diminshed at 4.7 hours.[3] Large animals in class III shock were subjected to graded ischaemia and were subsequently observed for evidence of neuromuscular recovery for 2 weeks. There was clear evidence that, in these animal experiments, the ischaemic time threshold was reduced to less than 3 hours.[4] This experiment was designed to delineate the relationship between time and restoration of blood flow and functional limb salvage.

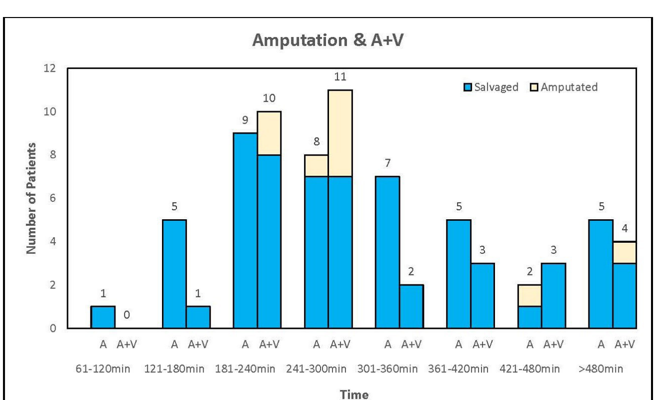

Figure 3 Distribution of amputations over time by arterial injury (A) and arterial injury with concomitant venous injury (A + V).

Those animal experiments did not take into consideration the confounding effect of collateral circulation to distal extremity musculature in preventing ischaemic necrosis. In real-world combat situations, a subset of injured limbs with axial arterial injury are well perfused by preserved collateral circulation. This led to survival of limbs for more than 12 hours of ischaemic period in contrast to the 6-hour ischaemic time limit hypothesis.[11 12] Hafez *et al* stated in regard to extremity arterial injuries, '*it is more relevant to identify signs of severe ischaemia such as compartmentalization or loss of sensation or function than to rely on the absolute ischaemic time for prediction of outcome*'.[13]

Previous studies of patients from the Sri Lankan Civil War with arterial injury alone compared with those with concomitant arterial and venous injury, clearly demonstrated that there is a statistically significant impact on rate of amputation in patients with combined injury.[14] Subsequent evaluation of patients with an injury of the popliteal artery showed that the addition of popliteal vein and skeletal trauma had higher rates of primary amputation.[15]

Findings of this study challenge the notion of the 6-hour critical ischaemic time threshold. Segmental injury and skeletal trauma were more significantly associated with ultimate amputation regardless of total ischaemic time. Concomitant venous injury and popliteal anatomy may have approached statistical significance, but this was limited due to the overall small numbers of amputations. Although fasciotomy is a limb salvage adjunct, it was statistically significantly correlated with amputation. This is likely due to the fasciotomies being performed to assess muscle viability with subsequent primary amputation when non-viability of muscles was discovered.

Considering these facts and experiences, multiple compounding factors should be taken into consideration before selecting limb for reconstructive efforts. These include; injury anatomy, injury physiology, concomitant skeletal trauma and venous injury in addition to the ischaemic time. Patients with multiple of these compounding factors should be identified and prioritised for early ischaemia limiting vascular adjuncts and expedited transfer to definitive vascular reconstruction from the point of injury.[16 17]

Our data represent a large cohort of arterial injuries with prolonged ischaemic time but it is limited by the data that are missing. In combat situations, it is often difficult to record data in a timely fashion and therefore we had to exclude 26 patients due to lack of recorded ischaemic time, of which 13 underwent amputation. This limitation and exclusion could result in bias in interpretation of ischaemic time and limb salvage rate.

CONCLUSION

There is a subset of extremity vascular injuries which has inherent or acquired paucity of collateral circulation. Although it did not reach statistical significance in this paper, inherent factors likely include popliteal anatomy. The acquired factors include associated skeletal trauma and segmental arterial injury while concomitant arterial and venous injury also trended towards significance. In these limbs, critical ischaemic time may be even less than 6 hours and needs to be prioritised for urgent vascular repair for optimal limb salvage. Further research should look into the clinical, biochemical and morphological markers that quantify the degree of muscle ischaemia to facilitate selection and prioritisation of limb revascularisation with the ultimate objective of functional limb salvage.

Correction notice This article has been corrected since it first published. Reference 9 has been added to the Introduction section.

Contributors ASR: data collection, data analysis, data interpretation, writing. MB: data interpretation, critical revision, literature search. CJF: data interpretation, critical revision. AJ: data analysis, data interpretation, writing. SPBT: data collection, critical revision. TJW: data interpretation, writing, critical revision.

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ORCID iD
T J Worlton http://orcid.org/0000-0002-6959-9985

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