# Management of penetrating injuries of the upper extremities

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**Abstract**

**Objectives**: Routine surgical exploration after penetrating upper extremity trauma (PUET) to exclude arterial injury leads to a large number of negative explorations and iatrogenic injuries. Selective non-operative management (SNOM) is gaining favour for patients with PUET. The present study was undertaken to assess the validity of SNOM in PUET and to present a practical management algorithm.

**Methods**: All subsequent patients presenting to a tertiary referral centre following PUET were included in this prospective cohort study. Patients were managed along Advanced Trauma Life Support (ATLS©) guidelines and based on clinical festations, either underwent emergency surgery or were treated conservatively with or without additional diagnostic investigations. Computed tomography angiography (CTA) was indicated by a preset protocol based on physical examination.

**Results:** During the 4-month study period, 161 patients with PUET were admitted. Sixteen (9.9%) patients underwent emergency surgery; revealing 14 vascular injuries. Another 8 (5.0%) patients underwent vascular exploration following CTA. The remaining patients (n=137) were managed non-operatively for vascular matters. Eighteen (11.2%) patients required semi-elective surgical intervention for fractures or nerve injuries. At follow up no missed vascular injuries were clinically detected.

**Conclusion:** Neither routine exploration, nor routine CTA, after penetrating trauma of the upper extremities is indicated. Stable patients should undergo additional investigation based on clinical findings only. SNOM is a feasible and safe strategy after PUET.

**Key Words:** Emergency surgery, penetrating trauma; upper extremity; vascular injury

## Introduction

Penetrating injury to the extremities accounts for about 50% of penetrating trauma, but overall is still very uncommon in West European countries.[1,2] The low incidence makes it difficult for trauma surgeons to gain experience in its management. Moreover, patients with penetrating injury usually present unexpectedly to the emergency department. This could lead to an inappropriate preparation for assessment, especially when the hospital is not an allocated trauma centre for such trauma with a protocol treatment strategy.

Penetrating upper extremity trauma (PUET) is considered a difficult injury to manage because vascular and nerve injuries are serious and may significantly impair outcome of the patient.[2,3] In the past, routine emergent exploration was common practise for the deeper penetrating trauma, resulting in a large number of unnecessary extremity explorations and iatrogenic injuries.[1,4] Although, rapid detection, localisation and specification of a vascular injury in these patients are essential for the effective management of PUET; it is ill-advised to perform diagnostic computed tomography angiography (CTA) or conventional angiography in every patient.[5,6,7] Over 90% of CTAs in these patients will be negative, representing a large cost as a screening tool.[7]

Based on the experience from high volume hospitals in developing countries, selective screening based on physical examination is gaining favour. The accuracy of physical examination to detect vascular injury is very high in patients after penetrating trauma.[6,8,9,10] Hard signs of a vascular injury (Table 1) mandate emergent surgical exploration, or, when the patient is hemodynamically stable, endovascular treatment could be considered.[7,11] Diagnostic CTA is indicated in hemodynamically stable patients with clinical signs of vascular injury (Table 1). Similar as in penetrating trauma of other body regions a selective non-operative management (SNOM) protocol should be used in PUET.[2, 8,9] Without signs of vascular impairment in PUET a conservative observational strategy is likely.[8]

The present study was undertaken to assess SNOM of PUET in a tertiary referral trauma centre (Groote Schuur Hospital, Cape Town), in which over 800 patients with penetrating trauma of the extremities present each year. Based on the results a management algorithm is proposed and adjusted towards health care in Western countries.

## Patients and methods

To create a database, details of all patients presenting with PUET to the Trauma Centre at Groote Schuur Hospital in Cape Town, South Africa, from June 2011 to October 2011 (4 months) were prospectively collected. Inclusion criteria were patients with PUET and age over 18 years. Patients who died within 24 hrs, due to other injuries were excluded from the study.

Age, gender, mechanism of injury, type of injury (vascular, orthopaedic, nerve), clinical manifestations and vitals, indications for additional investigations, treatment strategy and outcome of all patients were collected and analyzed.

All patients were initially resuscitated along Advanced Trauma Life Support (ATLS) guidelines. Hemodynamically stable patients, and patients who stabilized after immediate simple resuscitation, were first evaluated with a thorough history and clinical examination. Wounds were described by different anatomic zones of the arm (upper- or lower arm, elbow or cubital fossa, anterior-posterior, medial-lateral).

Special investigations were requested when indicated by preset protocol based on history and clinical manifestations. A routine X-ray was performed in case of gunshot injuries. Indications for CTA were symptoms suspected for vascular injury as found by clinical examination of the upper extremities (Table 1) in the presence of a viable limb. If any severe

injury was found by additional investigations and surgical care was needed, patients were immediately transferred to the operating room for surgical intervention.

Hemodynamically stable patients with a negative history and clinical examination suspicious of vascular injury were admitted to the trauma surgical ward, for observation and discharged after 24 hours. All patients were informed about alarm symptoms of vascular injury; if these occurred, patients were advised to return to the hospital immediately.

Hemodynamically unstable patients and those with ischemia were immediately transferred to the operating room. In actively bleeding patients haemorrhage control was attempted by using Foley catheter balloon tamponade (FCBT).[12] If haemorrhage control was not established, surgical exploration of the injured arm followed immediately. If haemorrhage was controlled by FCBT, CTA was performed to detect major arterial injury and, if positive, patients could still be transferred to the operating room or were treated by endovascular options. Without any serious arterial injury, the patient was observed for 24-48 hours, after which the Foley catheter was removed in the operating room. In case of re-bleeding, surgical intervention was performed.

**Results**

A total of 162 patients with PUET presented during the 4-month study period. One patient died of accompanied abdominal bleeding within 24 hours after admission and was excluded from the study. Some patients had multiple wounds to the upper extremities, with a total of 179 wounds in 161 patients (Table 2). Stab wounds (SW), or penetrating glass wounds were found in 128 (79.5%) patients (145 arms) and gunshot wounds (GSW) in the remaining 33 (20.5%) patients (34 arms).

Sixteen (9.9%) patients underwent emergency exploration because of active bleeding or hemodynamic instability, not improving during initial resuscitation or because other reasons mentioned in Table 3. In all but two patients, an arterial injury was detected during exploration that required repair.

A total of 24 (14.9%) patients underwent CTA (Table 3) for a suspected vascular injury. In 2 patients CTA was performed without relevant indication and both did not show any vascular injury. A total of 3 patients were initially treated with FCBT because of active bleeding. In one patient haemostasis could not be achieved and was subsequently emergently surgically treated. The other 2, in whom haemostasis was achieved, were observed and underwent diagnostic CTA within 24 hours. Only one of these patients showed an arterial injury, which was repaired during semi-elective explorative surgery. The Foley catheter of the patient, who did not need to undergo surgery, was removed in the operating room 2 days after patient's presentation; no re-bleeding occurred.

Overall, 16 (9.9%) patients underwent emergency exploration of the upper extremity, including two negative explorations. Eventually, another 8 (5.0%) patients underwent elective surgery for a vascular injury (Table 4); no patients were treated by radiological intervention. One-hundred and thirty-seven (85.1%) patients underwent non-operative management with observation only. Following observation, none of the patients subsequently needed surgical intervention to treat (late onset) vascular complications. Some of the later mentioned patients did undergo surgical treatment by orthopaedics (n=10) or plastic or neurosurgeons (n=8). In 3 patients the plastic surgeon joined the trauma surgeon during emergent exploration to repair nerve injury primarily.

The median hospital stay was 4 days (range 1-30 days). Longer hospital stay was related to associated injuries as listed in Table 2. One patient died of abdominal sepsis after penetrating chest and abdominal injury. Upper extremity related complications were surgical site

infection in 8 of the patients that underwent surgery. Loss of function or other nerve impairment was found in only 5 patients, besides the 11 patients that underwent surgical repair of damaged nerves. Long term functional outcome of these 11 patients was not known at the end of this study. Fractures of the upper extremity after penetrating injury were almost exclusively found after GSW. In one patient an ulnar shaft fracture was found in a patient with after SW in combination with blunt assault.

**Discussion**

In the Netherlands, as in the rest of West-Europe, the incidence of penetrating injury is rather low. In Dutch trauma centres there is definitely a lot less experience with the management of PUET than, for example, in the USA or South Africa. Due to this low incidence it is not possible for a trauma surgeon to gain experience with the management and treatment of this kind of trauma. Protocol management of PUET is lacking, causing obscurity, disagreement in diagnostic and treatment options, and an insufficient or incomplete management of this trauma patient. The lack of protocol assessment of patients suffering PUET increases the risk of mistakes and hampers good outcome.

In trauma centres that do treat a high number of patients with penetrating trauma, SNOM is becoming more and more accepted.[6,8] SNOM is based on clinical examination and additional investigations. Together they have shown to be a reliable indicator of clinically significant injury, with a sensitivity of 99% and a negative predictive value of 99% in patients with PUET.[5,13]

The present study was done in a high-volume, tertiary referral trauma centre for penetrating injuries, managing about 800 patients with penetrating extremity injury each year. The

management protocol for assessing and treating patients with PUET is based essentially on hemodynamic status, together with a thorough physical examination. Initial management of GSW and SW is similar; except for X-ray to rule out a fracture of the upper extremity is standard care in GSW patients. Adjuvant CTA is only indicated based on hard and subtle signs of vascular injury found during clinical assessment in hemodynamically stable patients.

At present, in most trauma centres CTA had replaced angiography as the preferred diagnostic tool in assessment of vascular injuries. An advantage of using angiography though, is the possibility of interventional procedures if indicated during the same session. Nevertheless, for diagnostic evaluation of PUET, CTA has several advantages over conventional angiography.[14,15] It is relatively fast, minimally invasive, has fewer potential complications and is available in most trauma centres in the Western countries. Moreover, no support of additional physician staff is required, unlike with conventional angiography, and structures other than vascular structures can be visualised on CTA (Figure 1). Most important it is a reliable and accurate investigation with a sensitivity and specificity of over 90% and 100% respectively, a positive predictive value of almost 100% and a negative predictive value of 98%.[16,17] Therefore CTA is more and more becoming the diagnostic tool of choice during initial evaluation of stable patients with vascular injury and thus very useful in patients with PUET.[32,33]

In this study the SNOM protocol for penetrating extremity injury was correctly executed with good persistence. A total of 10 patients had violation of the hospital protocol. Two patients with no signs of vascular injury underwent CTA. As both showed no vascular lesions, they were successfully treated conservatively. On the other hand 8 patients with hematoma accompanied with nerve injury underwent immediate surgical exploration. As they were hemodynamically stable they should have undergone protocol CTA. Two of those patients

showed no vascular injury during exploration; surgery could have been withheld if CTA was performed.

The use of FCBT has been shown to be beneficial in penetrating injury of the neck and extremities.[12, 18] This procedure allows for rapid haemorrhage control and stabilization of patients, giving the opportunity to visualize any vascular injury on CTA. Especially venous injuries are compliant to FCBT and in those patients FCBT is often definitive treatment.[12] If haemostasis cannot be achieved by FCBT, emergency exploration is indicated. Alternatively, temporary haemorrhage control can be achieved by using a tourniquet or haemostatic dressings before surgery or FBCT. After FBCT diagnostic CTA should be performed; CTA is useless with a tourniquet in place. In this study FCBT was used in 3 patients, of whom one failed and subsequently underwent emergent exploration with brachial artery repair.

Vascular observational management after PUET was applied in 85% of patients without or after CTA assessment. During follow up none of the patients who were conservatively treated and observed presented with a missed vascular injury. This indicates that initial conservative management (or SNOM) of patients with PUET is feasible and safe.

The total surgical treatment rate was 26% (24 vascular injuries, 10 fractures, 8 exclusively nerve injuries), indicating that PUET should be considered a serious injury that requires intensive and thorough assessment of the arm.[19] The prevalence of vascular injury that needs intervention is 15% after PUET. Frequently PEUT is associated with penetrating injuries (this study 38% of cases), that possibly needs to be managed first or distracts the physician’s attention away from the injuries of the upper extremity. Eventually missed or even delayed assessment of PUET may significantly impair outcome of the patient. This is best prevented by protocol-driven management strategies. In penetrating trauma the different protocols could be combined.

In summary, clinical examination has a high negative predictive value for the absence of any injury, and can therefore dictate CTA to prove or exclude clinically significant vascular injuries in PUET. The low failure rate in this study further validates the SNOM protocol for initial management of PUET. Following the results of this study, we present an algorithm for the initial management of PUET in Western Countries (Figure 2). Vascular assessment after GSW should not be different from that of SW, although one must realise that the severity of injury usually is more extensive due to high energy and an X-ray is performed to exclude a fracture.

**Author Contributions**

Oscar JF van Waes: Data interpretation and writing

Pradeep H Navsaria: Study design, data collection supervision, writing

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## Tables

**Table 1.** Signs of arterial injury

| |
|---|
| **Hard signs** |
| Active haemorrhage |
| Absent distal pulses or ischemia |
| Expanding or pulsatile hematoma |
| Bruit or thrill |
| **Soft signs** |
| Subjective reduced or unequal pulses |
| Large non-pulsatile hematoma |
| Orthopaedic injuries carrying a high index of suspicion of vascular injury |
| Neural injury |
| History of bleeding |

**Table 2.** Demographics of 161 patients with penetrating upper extremity injury

| | |
|---|---|
| Sex ratio (M:F) | 140:21 |
| Number of upper extremities injured | 179 |
| Median age, years (range) | 27 (16-71) |
| **Penetrating upper extremity injury** | |
| Glass | 13 |
| Stab wound | 132 |
| Gunshot wound | 34 |
| *Zone of extremity injury* | |
| *Right arm* | |
| Upper | 30 |
| Elbow, cubital fossa | 6 |
| Lower | 25 |
| Upper and lower | 4 |
| *Left arm* | |
| Upper | 53 |
| Elbow, cubital fossa | 4 |
| Lower | 40 |
| Upper and lower | 11 |
| *Bilateral injury* | 6 |
| **Suspected extremity injury** | |
| *Vascular* | |
| Emergent exploration[1] | 16 (14) |
| Computed tomography angiography[1] | 24 (11) |
| *Fracture* | |
| X-ray[2] | 19 (10) |
| *Nerve* | |
| Physical examination[2] | 35 (11) |

| | |
|---|---|
| **Accompanied penetrating injury** | |
| Neck | 14 |
| Neck and chest | 4 |
| Chest | 19 |
| Abdomen | 12 |
| Chest and abdomen | 6 |
| Thigh | 6 |

*1. Values in parentheses are numbers of positive findings;*

*2. Values in parentheses are numbers of surgical intervention because of injury.*

**Table 3.** Indications and results of emergent surgical exploration or additional vascular investigations

| **Indication for emergency exploration** | **n** |
|---|---|
| Active haemorrhage or shock | 4 (4) |
| Absent pulses | 3 (3) |
| Foley catheter balloon tamponade failure | 1 (1) |
| Hematoma accompanied with neural injury | 8 (6) |

| **Indication for computed tomography angiography** | **n** |
|---|---|
| Absent or diminished pulses | 12 (6) |
| Large hematoma | 3 (2) |
| Foley catheter balloon catheter | 2 (1) |
| Bruit | 1 (1) |
| Injury at cubital fossa | 3 (1) |
| Fracture and neural injury | 1 (0) |
| Not specified | 2 (0) |

*Values in parentheses are numbers of positive findings of arterial injury.*

**Table 4.** Summary of arterial injuries and their management

| **Site of injury** | **Treatment** |
|---|---|
| During emergency exploration | |
| *Brachial artery* | Venous interposition graft with fasciotomy (5) |
| | Primary repair (3) |
| | Primary repair with fasciotomy (3) |
| *Radial artery* | Ligation (2) |
| | Ligation with fasciotomy |
| After Computed tomography angiography | |
| *Axillary artery* | |
| Occlusion | Primary repair |
| False aneurysm | Primary repair |
| *Brachial artery* | |
| Occlusion | Venous interposition graft (2) |
| AV fistula with basilica vein | Venous interposition graft |
| Active bleeding | Primary repair (2) |
| False aneurysm | Primary repair |
| False aneurysm | Conservative |
| *Posterior circumflex humeral artery* | |
| Active bleeding | Conservative |
| *Ulnar artery* | |
| False aneurysm | Conservative |

*Values in parentheses are number of patient, if more than one*

**Figures**

**Figure 1**. Computed Tomography Angiography of a patient without peripheral pulses at physical examination, showing an occlusion of the brachial artery, which was subsequently surgically reconstructed with venous interposition grafting.

**Figure 2.** Algorithm for initial management of patients with penetrating upper extremity injury

*ATLS = Advanced Trauma Life Support; CTA = Computed tomography angiography; GSW = Gunshot Wound*