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Evaluation of open fractures associated with vascular and visceral injuries: A prospective study

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Abstract:
High energy open fractures are associated with vascular and visceral injuries that increase the risk of morbidity and limb loss. This prospective observational study evaluated 100 patients with open fractures for associated vascular and visceral injuries, assessing mechanism of injury, fracture characteristics, Gustilo-Anderson classification, management and early outcomes. Road traffic accidents (61%) were the leading mechanism, the tibia (49%) was the most commonly fractured bone and 55% of fractures were Gustilo type III; vascular and visceral injuries occurred in 26% and 14% of patients, respectively, with higher rates in more severe fractures ($p<0.001$). Patients with vascular injuries required more vascular repairs, fasciotomies and external fixation and had longer hospital stays, while multidisciplinary management achieved limb salvage in most patients. These findings advance knowledge by emphasizing early recognition of vascular and visceral injuries in severe open fractures to facilitate timely multidisciplinary management and minimize complications.

Keywords: Open fractures, vascular injury, visceral injury, Gustilo-Anderson classification, limb salvage, polytrauma, external fixation, trauma surgery

Background:
Open fractures are among the worst injuries of the musculoskeletal system to encounter in trauma practice because of the magnitude of the contamination, vascular problems, soft tissue injury and risk of developing infection, non-union and limb loss. The severity of these injuries varies with the amount of soft tissue, neurovascular and visceral involvement as well as the extent of bony disruption **[1]**. Open fractures require coordinated prevention of fracture-related infection, including antimicrobial prophylaxis, wound debridement and irrigation, skeletal stabilization, and soft-tissue coverage **[2]**. High energy trauma, specifically Road traffic accidents, falls from height and injuries from industrial incidents are the most common causes of open fractures, most of which occur in economically active, young people **[1].** Open fractures remain the most widely used system for the classification of open fractures according to their wound size, contamination and soft tissue damage and continue to be the basis for treatment decisions and assessment of prognosis. Epidemiological studies have demonstrated the lower extremities, particularly the tibia are most commonly affected **[3]**. In a recent four-year observational study of 368 open fractures, secondary infection occurred in 13.3% of cases; bone loss, crush injury, and pelvic trauma were identified as risk factors **[4]**. The principles behind management of open fractures are that broad and early coverage of the wound area with a broad-spectrum antibiotic, meticulous debridement of the wound, prompt fracture stabilization and soft tissue coverage are all important to the recovery, with potential implications for increased morbidity, longer hospitalizations, higher amputation rates and poor functional outcomes if these principles are not followed **[2].** New guidelines from the Surgical Infection Society recommend early starting of appropriate antimicrobial therapy based on the degree of severity of the injury to limit infection and to increase the chances of limb salvage **[5].** The Gustilo–Anderson classification also informs antimicrobial prophylaxis, although the choice and duration of antibiotic therapy remain variable across institutions **[6]**. In a secondary analysis of 3,331 patients, Lin *et al.* found no statistically significant differences in infection odds between the antibiotic regimens compared; the authors concluded that the optimal prophylactic regimen remains uncertain **[7]**. The Eastern Association for the Surgery of Trauma (EAST) has emphasized evidence-based antibiotic protocols and with the advancement of ortho-plastic surgery, innovative early operative treatment of complex open fractures has improved the chances of limb salvage while reducing the likelihood of infection. A modern approach to treatment promotes a multidisciplinary management strategy that incorporates management by an orthopedic surgeon, a traumatologist, a plastic surgeon and a vascular surgeon, in order to ensure early fracture stabilization, early vascular repair (when necessary) and soft tissue reconstruction **[8]**. All these well-coordinated interventions have contributed to better limb salvage results and fewer postoperative complications. Current systematic management strategies also include holistic assessment of associated vascular, visceral and neurological injuries, especially for high energy trauma victims **[9, 10].** In addition there has been further improvement in the implementation of trauma standard care pathways and implementation of British Orthopaedic Association Standards for Trauma (BOAST) guidelines which include early antibiotics, prompt debridement and specialist orthoplastics care for severe open fractures which have shown to influence limb viability and patient outcomes **[11].** Associated injuries that have the greatest influence on the limb viability and patient outcome include vascular damage. When arterial injury is not diagnosed in a timely manner, it can cause ischemia of the extremity, compartment syndrome, permanent tissue death and amputation **[12].** Therefore, it is of interest to assess the pattern of open fractures with vascular and visceral injuries, the frequency of occurrence of the injuries and its impact on early clinical management and hospital outcome.

Materials and Methods:
Study design:
This prospective, observational study was performed to assess the distribution of open fractures in patients with vascular and visceral injuries among trauma patients.

Study setting and duration:
Following approval by the Institutional Ethics Committee, the study was conducted in the Dept of Orthopaedics along with the respective departments (General Surgery, Vascular Surgery and Radiodiagnosis) in a tertiary care teaching hospital for 2 years.

Confidential informed consent forms were signed by all eligible patients or there legally authorized representatives.

Sample size:
Enrolled were a total of 100 consecutive patients who fit the criteria for open fracture.

Study population:
The clinically and radiologically assessed patients were those with open fractures who had been injured but without an associated vascular and visceral injury.

Inclusion criteria:
[1] Patients over 18 years of age.
[2] Clinically and radiographically diagnosed open fractures of upper & lower limbs
[3] Presentation within 24 hours after injury.
[4] Written informed consent of the patient.

Exclusion criteria:
[1] Closed fractures and pathological fractures.
[2] Isolated injuries of hands or feet with no significant involvement of the major skeletal system.
[3] History of previous surgery/treatment for the affected extremity.
[4] Patients who died before a full evaluation has been done.
[5] Patients who are not keen on the intervention.

Study procedure:
Demographic information and mechanism of injury and time since trauma were obtained on admission. Initial assessment was carried out based on Advanced Trauma Life Support (ATLS). The Gustilo-Anderson classification system was used for classification of open fractures. The physical findings obtained at the clinical examination were wound appearance, fracture site, contamination, distal pulses, capillary refill, distal extremity temperature, motor function and sensory function. In all patients, radiographs were taken of the injured extremity. Handheld Doppler ultrasonic adjustable examination was provided for suspected vascular lesions followed by computed tomography angiography (CTA) or conventional angiography if necessary. Vascular injuries were defined as any arterial transection, partial laceration, thrombosis, intimal injury, pseudoaneurysm or active bleeding. Examination, focused assessment with sonography for trauma (FAST), ultrasonography or contrast enhanced computed tomography (CECT) were used as necessary as well as exploratory laparotomy to assess for associated visceral injuries, which were diagnosed. Literature pertaining to liver, spleen, kidney, bowel, urinary bladder, thoracic organs and other viscera injuries were recorded. Tetanus prophylaxis, intravenous antibiotic, wound irrigation, debridement if clinically indicated, fracture stabilisation, vascular repair if indicated and treatment of associated visceral injuries were routinely performed in all patients in the manner recommended by institutions and were not contingent upon the decision.

Outcome measures:
Primary outcome:
Incidence and pattern of vascular and visceral injuries associated with open fractures.

Secondary outcomes:
[1] Fractures classified in accordance with the Gustilo-Anderson classification.
[2] Mechanism/Anatomical site of injury.
[3] Types of vascular and visceral injuries.
[4] Surgical procedures performed.
[5] Complications, in-hospital mortality, hospital stay, Limb salvage

Statistical analysis:
The data was entered in an excel sheet and analysed with SPSS soft 25.0. All continuous variables were expressed in terms of mean ± SD value and all categorical variables were presented in frequencies and percentages. Categorical variables were analysed using Chi-square test or Fisher's exact test while continuous variables were analysed using the independent Student's t-test. Logistic regression analysis was used to determine variables associated with vascular injury. A p-value <0.05 was deemed as statistically significant.

Results:
In total 100 patients with open fractures were studied. At the time of admission, every patient was carefully clinically, radiographically and vascularly examined. Most had injuries as a result of high-energy trauma and the lower extremity was the most common location. Associated vascular and visceral injuries were diagnosed on clinical examination and with the support of appropriate imaging. Patients with vascular compromise had immediate vascular surgery when necessary. Most patients were 18–30 years old (38%), followed by those aged 31–45 years (34%). Males predominated (74%). The majority of injuries were by road traffic accidents (61%) followed by falls from height (22%), which demonstrates the high-energy nature of the causes as shown, in **Table 1.** Bones are most common to be involved, with tibia and fibula being the most frequently involved bones (49%). The majority were common type II fractures (29%) and there was a significant amount of severe trauma with a total 55% of all open fractures being type IIIA, IIIB and IIIC as shown in **Table 2.** Twenty-six percent of patients had associated vascular injuries and 14% had concomitant injuries to internal organs. As severity of open fractures increased so did the frequency of both vascular and visceral injuries. Vascular injury was found across all Type IIIC fractures and there was a strong association ($p<0.001$) as shown in **Table 3.** More emergent vascular repair, fasciotomies and external fixation were necessary for patients with vascular injury. Of those with vascular injury, 84.6% had a limb salvaged with 15.4% being amputated. Patients with vascular injury had significantly longer hospital stay than those without vascular injury (16.8 ± 5.2 days versus 10.4 ± 3.6 days, respectively, $p<0.001$) as shown in **Table 4.**

Table 1: Demographic characteristics and mechanism of injury (n = 100)

Variable	Number (n)	Percentage (%)
Age group (years)		
18–30	38	38.0
31–45	34	34.0
46–60	20	20.0
>60	8	8.0
Gender		
Male	74	74.0
Female	26	26.0
Mechanism of injury		
Road traffic accident	61	61.0
Fall from height	22	22.0
Industrial injury	11	11.0
Assault/Others	6	6.0

Table 2: Distribution of open fractures and associated injuries (n = 100)

Variable	Number (n)	Percentage (%)
Site of fracture		
Tibia/Fibula	49	49.0
Femur	23	23.0
Forearm bones	15	15.0
Humerus	8	8.0
Others	5	5.0
Gustilo-Anderson classification		
Type I	16	16.0
Type II	29	29.0
Type IIIA	24	24.0
Type IIIB	20	20.0
Type IIIC	11	11.0

Table 3: Pattern of vascular and visceral injuries according to Gustilo classification

Gustilo type	Total cases	Vascular injury n (%)	Visceral injury n (%)
Type I	16	0 (0.0)	0 (0.0)
Type II	29	2 (6.9)	1 (3.4)
Type IIIA	24	5 (20.8)	3 (12.5)
Type IIIB	20	8 (40.0)	5 (25.0)
Type IIIC	11	11 (100.0)	5 (45.5)
Total	100	26 (26.0)	14 (14.0)

Chi-square = 31.82, p < 0.001

Table 4: Management and early clinical outcomes according to vascular injury

Outcome	Vascular injury (n=26)	No vascular injury (n=74)	p value
Emergency vascular repair	21 (80.8%)	0	—
Fasciotomy performed	12 (46.2%)	5 (6.8%)	<0.001
External fixation	19 (73.1%)	35 (47.3%)	0.028
Limb salvage	22 (84.6%)	74 (100%)	0.004
Amputation	4 (15.4%)	0	0.004
Mean hospital stay (days)	16.8 ± 5.2	10.4 ± 3.6	<0.001

Discussion:

In the current prospective study, it was shown that high energy trauma, particularly road traffic accidents was the most common mechanism of fracture with associated vascular and visceral injuries and that the pattern of open fractures was unique to each type of vascular and visceral injury. Tibia was the most common bone affected and over half of the patients had Gustilo type III fractures. Vascular injuries were associated in 26% of patients and 14% had visceral injuries. In both cases there was a great increase in the frequency of both injuries depending on the severity of the fracture, which suggests the need for immediate multidisciplinary assessment. Combined orthopedic and vascular trauma is linked with higher complication rates of development of limb ischemia, compartment syndrome, infection and amputation if the vascular damage is not detected early, emphasized by Kontopodis *et al.* **[13].** Castro *et al*. reported that in the long bone fractures three factors should be taken into consideration for management, which is personalized, based on the results of the limb ischemia, fracture stability and the patient condition. Vascular repair and temporary stabilization of fracture produced better limb salvage rate in the early repair group. The same principles applied in the above-mentioned own experience in cases of emergency vascular repair and external fixation, include the ultimate success of the overall limb salvage rate in the present study, 84.6% **[14].** Su *et al.* showed that the presence of severe soft tissue injury, inability to palpate distal pulses and high-grade open fractures were important factors to predict the presence of vascular injury. Similarly, in the current study, vascular injuries were rare in Gustilo type I and II injuries and occurred more frequently in Gustilo type III injuries especially IIIC fracturing, in which vascular injury was also present in all the patients where successful results of treatment with an open fracture relies on timely revascularization, extensive debridement, the stability of the skeleton and cooperation in orthoplastic reconstruction **[15].** Zolper *et al.* showed that better management of open fractures with vascular injuries based on aggressive debridement, skeletal fixation and orthoplastic reconstruction. The good initial outcomes seen in the present study validate these treatment principles **[16].** Meakes *et al.* reported that investigation of CT scan findings showed that vascular and soft tissue injuries are significant factors that affect long-term functional recovery following polytrauma. While long term follow up was not under the scope of current research, because patients with injuries experienced longer duration of hospital and also required sophisticated surgical management, which showed a greater rehabilitation burden **[17].** Scalea *et al.* showed that patients with vascular injury had longer hospital layups and more complex surgical management, which indicates a higher rehabilitation burden; although long-term follow-up was not a focus, they found temporary external fixation to be an effective damage control surgical management, allowing for vascular repair prior to definitive fracture fixation **[18].** Consistent with this, appropriately timed fracture stabilization leads to more rapid recovery and fewer complications, as noted by Vallier *et al.* and observed in the present series of fractures **[19].** Gilbert *et al.* showed that vascular injury is an independent risk factor for prolonged hospitalization and increased complication rates. Consistent with their conclusions, the patients in the current study who had vascular injuries had a higher rate of vascular procedures, fasciotomy and a significantly longer hospital stay compared to those without vascular injuries **[20].** O'Malley *et al.* have also found that vascular injuries are not as well-known as they should be and emphasized that routine vascular evaluation with Doppler ultrasonography or computed tomography (CT) angiography of the injured extremity should be performed in severe open tibial fractures **[21].** The prospective design and uniform assessment of vascular and visceral injuries enhance the present study. Limitations include its single-center design, relatively small sample size and not enough long term follow-up

functional data. Further validation of these results and refinement of future management protocols for the management of complex open fractures through larger multicenter studies is needed.

Conclusion:

Open fractures with vascular and visceral injuries are more often encountered in severe (Gustilo type III) fractures, after high-energy trauma. Securing early clinical and radiological diagnosis of vascular compromise, rapid fracture stabilisation, early vascular repair and multi-disciplinary support are crucial to the achievement of good limb salvage and minimisation of complications. All severe open fractures should include a routine evaluation and management of associated vascular and visceral injuries.

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