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Management and Outcomes of Aerodigestive Injuries in Penetrating Neck Trauma in Yemen

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Abstract

Background: Penetrating neck trauma (PNT), involving the aerodigestive system, is a life-threatening condition. Effective management is crucial, particularly in resource-limited conflict zones.

Objective: To evaluate the management and outcomes of PNT at a military hospital in Sana'a, Yemen.

Methods: We retrospectively reviewed the records of 50 patients who underwent PNT (January 2018 and March 2023). This analysis included 30 patients with confirmed aerodigestive tract injuries.

Results: All patients were male (90% aged 20–30 years). Gunshot wounds (67%) predominated, with 77% presenting within 24 h; all were Zone II injuries. The most common signs were dyspnea (50%) and dysphagia (59%). Surgical exploration was indicated in 50% of patients. Single-structure injuries (77%) primarily involved the pharynx (53%) or larynx (43%). Pharyngeal injuries were often managed conservatively (63%), and all patients with esophageal injuries required surgical repair. Postoperative infections occurred in 13% (airway) and 17% (digestive) of cases. The overall survival rate was 96.7%, with 66.7% of patients surviving without morbidity, 30% surviving with morbidity, and 3.3% mortality.

Conclusion: Despite significant infection rates, high survival rates are achievable in this resource-limited conflict setting. Context-specific protocols that prioritize rapid pre-hospital care, multidisciplinary management, and robust infection control are vital.

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INTRODUCTION

Penetrating neck trauma is a life-threatening condition caused by the density of vital structures in the neck, including the airway, digestive tract, and major vasculature [1]. Aerodigestive injuries affecting the larynx, trachea, pharynx, or esophagus are particularly critical because they can cause airway compromise, severe bleeding, or infection, leading to rapid deterioration if not managed promptly [2].

Management of penetrating neck trauma has evolved significantly. Historically, mandatory surgical exploration has been the standard; however, it often results in non-therapeutic interventions [3]. Modern approaches favor selective management guided by clinical presentation and advanced imaging, such as computed tomography angiography (CTA), which offers high sensitivity in detecting vascular and aerodigestive injuries [4]. Endoscopy, including bronchoscopy and esophagoscopy, complements CTA by enabling direct visualization of mucosal injuries, although its optimal timing remains debatable

[5]. Despite these advances, penetrating neck trauma remains a challenge and requires multidisciplinary care from trauma surgeons, otolaryngologists, intensivists.

In conflict zones such as Yemen, penetrating neck injuries are increasingly common due to ongoing violence, resource constraints, and military trauma patterns that complicate management [6]. Data on aerodigestive injuries in such settings are scarce, hindering the development of context-specific guidelines. In particular, there is a paucity of published data detailing the management strategies and outcomes of aerodigestive injuries resulting from penetrating neck trauma, specifically within Yemen's resource-limited conflict settings. Therefore, this retrospective study evaluated the management and outcomes of aerodigestive injuries associated with penetrating neck trauma at the General Military Hospital in Sana'a, Yemen, from 2018 to 2023. This study aimed to offer commentary on trauma care in resource-limited conflict settings and inform local protocols by analyzing patient demographics, injury characteristics, diagnostic methods, treatment strategies, and clinical outcomes.

MATERIAL AND METHODS

Study Design

This retrospective descriptive study analyzed the management and outcomes of aerodigestive injuries in patients with penetrating neck trauma at the General Military Hospital in Sana'a, Yemen, from January 2018 to March 2023.

Study Population

We reviewed the medical records of 50 patients with penetrating neck trauma admitted to the Department of General Surgery. Of these, 30 patients with aerodigestive injuries (larynx, trachea, pharynx, or esophagus) were included in the study. The inclusion criteria were as follows:(1) confirmed aerodigestive injury via clinical, imaging, or surgical findings and (2) admission during the study period. The exclusion criteria were as follows: (1) death during initial resuscitation or emergency surgery (n=5), (2) blunt neck trauma (n=10), and (3) penetrating neck trauma without aerodigestive involvement (n=5). A flow diagram of the patient selection process is presented (Figure 1).

Data Collection

Data were extracted from the medical records using a standardized form developed and piloted by the research team to ensure consistency. Variables included:

- **Demographics**: Age and sex.
- **Injury Characteristics**: Mechanism (e.g., gunshot, blast), time from injury to presentation, and neck zone (I, II, or III).
- **Clinical Presentation**: Hard signs (e.g., dyspnea and active bleeding) and soft signs (e.g., dysphagia and subcutaneous emphysema).
- **Diagnostic Methods**: X-rays with water-soluble contrast, computed tomography angiography (CTA), or endoscopy (bronchoscopy and esophagoscopy).
- **Management**: Indications for surgical exploration, treatment approaches (conservative or surgical), and injured structures.
- **Outcomes**: Complications, length of hospital stay, and survival status (with or without morbidity). Associated injuries (e.g., chest and head injuries) were also documented. The data were cross-checked by two investigators to minimize errors, and discrepancies were resolved by consensus.

Outcome Measures

The primary outcome was patient survival, which was categorized as survival without morbidity, survival with morbidity, or mortality. Secondary outcomes included complication rates, length of hospital stay, and effectiveness of diagnostic and treatment strategies, which were assessed by the proportion of injuries detected and successfully managed.

Statistical Analysis

Data were analyzed using SPSS version 26 (IBM Corp., Armonk, NY, USA). Continuous variables are reported as mean $\pm$ standard deviation or median (interquartile range) based on normality, assessed using the Kolmogorov-Smirnov test. Categorical variables are presented as frequencies and percentages of the total. Comparisons were performed using the Student's t-test for normally distributed continuous variables, the Mann-Whitney U test for non-normal data, and the chi-square or Fisher's exact test for categorical variables. The Injury Severity Score (ISS) was calculated using the MDApp tool to evaluate injury severity and its association with outcomes, and correlations were assessed using Spearman's rank test. Statistical significance was set at $P < 0.05$.

Ethical Considerations

This study complied with the Declaration of Helsinki and was approved by the Ethics Committee of the General Military Hospital of Sana'a. Permission was obtained from the medical record department of the hospital. The requirement for informed consent was waived because of the retrospective design; however, patient confidentiality

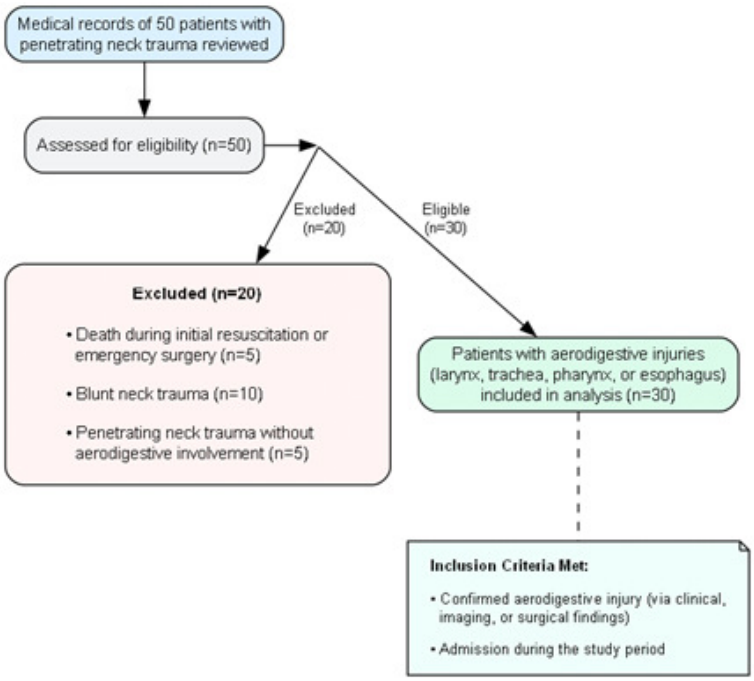

Figure 1. Flow diagram of patient selection.

was maintained by anonymizing data.

RESULTS

Patient Characteristics and Injury Profile

We analyzed data from 30 male patients with aerodigestive injuries due to penetrating neck trauma, all involving Zone II of the neck (Figure 1). Most patients (90%, n=27) were aged 20–30 years, 67% (n=20) had gunshot wounds, and 33% (n=10) had blast injuries. Injuries occurred within 24 h in 77% (n = 23) of the patients. Associated injuries occurred in 83% (n=25) of the patients, primarily in the chest (43%, n=13) (Table 1).

Clinical Presentations

Half of the patients (50%, n=15) were hemodynamically stable at presentation. Dyspnea was the most common hard sign (50%, n=15), followed by air or saliva leakage from the wound (23%, n=7 for each). Dysphagia (59%, n=18) and subcutaneous emphysema (57%, n=17) were the predominant soft signs (Table 2).

Diagnostic Modalities

Diagnostic modalities (X-rays with water-soluble contrast, CTA, or endoscopy) were used in 50% (n=15) of the patients, detecting 80% (n=12) of aerodigestive injuries in this subgroup. Immediate surgical exploration was indicated for airway compromise in 50% (n=15) of the cases, with the remainder explored based on imaging findings. Most injuries (77%, n=23) involved a single structure, primarily the pharynx (53%, n=16) or larynx (43%, n=13). Associated neck injuries (e.g., jugular vein and cervical spine injuries) were less common (Table 3).

Treatment Approach and Outcomes

Pharyngeal injuries were managed conservatively in 63% (n=10) of the cases, while laryngeal injuries often required primary repair with temporary tracheostomy (69%, n=9). All esophageal injuries (100%, n=3) underwent primary repair (Table 4). Complications included infections in 13% (n=4) of the airway injuries and 17% (n=5) of the digestive injuries. The length of hospital stay was less than 2 weeks in 37% (n=11), 2–4 weeks in 37% (n=11), and more than 4 weeks in 27% (n=8) of the patients. The survival rate was 97% (n=29), with 67% (n=20) surviving without morbidity and 3% (n=1) surviving with mortality (Table 5). The median Injury Severity Score (ISS) was 16 (IQR, 12–22), with no significant correlation with mortality (P=0.32).

DISCUSSION

This retrospective study of 30 patients at the General Military Hospital in Sana'a, Yemen, provides critical insights into the management and outcomes of aerodigestive injuries in penetrating neck trauma within a resource-limited conflict setting. The 97% survival rate, with 67% of patients surviving without morbidity, reflects the effectiveness of prompt multidisciplinary care, despite challenges such as limited access to advanced diagnostics and antibiotics. These outcomes compare favorably with

Table 1. Patient Characteristics and Injury Profile

Characteristic	Frequency (n)	Percent (%)
Age		
20–30 years	27	90
≥30 years	3	10
Sex		
Male	30	100
Mechanism of Injury		
Gunshot wound	20	67
Blast injury	10	33
Zone of Neck Injury		
Zone II	30	100
Time to Presentation		
≤24 hours	23	77
>24 hours	7	23
Associated Injuries		
Any	25	83
Chest	13	43
Head	4	13
Upper limb	4	13
Vertebral column	2	7
Pelvis	1	3
Lower limb	1	3

Table 2. Clinical Presentations

Presentation	Frequency (n)	Percent (%)
Hemodynamic Stability		
Stable	15	50
Unstable	15	50
Hard Signs		
Dyspnea	15	50
Air leakage from wound	7	23
Saliva leakage from wound	7	23
Central neurological deficit	2	7
Soft Signs		
Dysphagia	18	59
Subcutaneous emphysema	17	57
Dysphonia	13	43
Stable hematoma	13	43
Peripheral neurological deficit	1	3

those of the studies conducted in other settings. Ghnnam et al. [7] reported a 95% survival rate in a Saudi Arabian civilian cohort, whereas Mahmoodie et al. [8] reported a higher mortality rate (8%) in Iran, which was attributed to delayed presentation. Similarly, Burgess et al. [9] reported a 90% survival rate for penetrating neck injuries in a South African trauma center, although the injury spectrum was broader. The lower mortality in our study likely stems from rapid prehospital transport, with 77% of patients presenting within 24 hours, and a robust trauma system involving trauma surgeons, otolaryngologists, and intensivists.

Infections were the most prevalent complications, affecting 13% of airways and 17% of digestive injuries, consistent with previous reports. Asensio et al. [10] documented infection rates of 15–20% in penetrating neck trauma, highlighting the risk of contamination in high-energy injuries such as gunshots. In our cohort, the high infection rate may reflect resource constraints in the conflict zone, such as limited sterile surgical environments and inconsistent antibiotic availability. Holliday et al. [11] found that extended prophylactic antibiotic use ($>$24 h) in penetrating neck aerodigestive injuries was associated with higher infection (22% vs. 3%, P=0.036) and leak rates (15% vs. 0%, P=0.034) than limited use ($\leq$24 h), with no reduction in reintervention or mortality, suggesting that prolonged prophylaxis may not improve outcomes. Implementing limited-duration antibiotic protocols in Yemen could mitigate complications, along with enhanced infection control measures, such as improved wound care training for surgical staff. The predominance of conservative management for pharyngeal injuries (63%) contrasts with surgical approaches in high-resource settings [7]. For instance, Vassiliuet al. [12] advocated surgical repair for most pharyngeal injuries to prevent fistulae; however, resource constraints in our resource-limited setting necessitated selective intervention. All patients with esophageal injuries in our study underwent primary repair, in accordance with guidelines to prevent mediastinitis. Stanley et al. [13] emphasized early repair within 24 hours, which our cohort achieved, likely contributing to the low fistula rate (10%).

The cohort's demographics—90% aged 20–30 years and all males—reflect the military population, which is consistent with studies on combat-related injuries [14]. This contrasts with civilian studies, such as Ghnnam et al. [7], who reported a broader age range (15–60 years) and 10% female patients. Gunshot wounds (67%) and blast injuries (33%) were predominant in our study, reflecting conflict-related trauma, unlike stab wounds in the civilian setting. Shiroff et al. [15] noted that stab wounds, which are common in urban U.S. centers, are less likely to cause aerodigestive injuries owing to lower energy transfers. All injuries in our study occurred in Zone II, likely due to military weaponry trajectories aligning with Cruvinel Neto et al. [16] in Brazil, but differed from Breeze et al. [17], who reported a more distributed pattern in U.S. military cohorts.

The diagnostic modalities used in 50% of the cases detected 80% of aerodigestive injuries, supporting com-

Table 3. Diagnostic Methods and Injury Patterns

Variable	Frequency (n)	Percent (%)
Diagnostic Modalities Used		
Yes	15	50
No	15	50
Number of Injured Structures		
Single	23	77
Multiple	7	23
Aerodigestive Structure Injured		
Pharynx	16	53
Larynx	13	43
Trachea	5	17
Esophagus	3	10
Associated Neck Injuries		
Jugular vein	1	3
Cervical spine	2	7
Brachial plexus	1	3
Thyroid gland	2	7
Hyoid bone	2	7
Indication for Surgical Exploration		
Airway compromise	15	50
Imaging findings	15	50

puted tomography angiography (CTA) as a primary tool for hemodynamically stable patients. Inaba et al. [18] reported 95% sensitivity for CTA in detecting vascular injuries; however, Paladino et al. [3] noted a lower sensitivity (70%) for esophageal injuries, suggesting a role for endoscopy. The limited use of endoscopy in our study, possibly due to resource constraints such as equipment shortages, may have resulted in missed injuries. Future investments in portable diagnostic tools, such as handheld ultrasound and low-cost endoscopes, could enhance detection rates in conflict zones.

Injury Severity Score (ISS) analysis (median, 16; IQR, 12–22) showed no significant correlation with mortality (P=0.32), possibly because of the small sample size. This finding contrasts with that of Schroll et al. [19], who found that ISS was predictive of penetrating trauma outcomes. Our findings suggest that timely intervention may mitigate the impact of injury severity in cases of aerodigestive tract injury, although larger studies are needed.

Beyond the novelty of reporting from a conflict zone, a key strength of this study is the contribution of focused data on aerodigestive injuries in penetrating neck trauma from Yemen, an underrepresented region in medical literature. Furthermore, the study benefited from a relatively detailed dataset of injury characteristics and initial management of the included cohort, facilitated by the use of a standardized data collection form and cross-verification by two investigators despite the challenging environment. However, several limitations of this study should be considered when interpreting the findings.

This study had several inherent limitations. The **retrospective design** relied on existing medical records, which, despite cross-verification, may be subject to information bias owing to variability in documentation within a resource-limited conflict setting. This design precludes the establishment of a causal relationship. The **small sample size (n=30)** limits the statistical power, particularly for subgroup analyses, and means that the reported prevalence of complications or treatment successes should be interpreted with caution, wider confidence intervals should be applied, and rarer events may

Table 4. Treatment Approaches for Aerodigestive Injuries

Treatment Approach	Frequency (n)	Percent (%)
Pharyngeal Injury (n=16)		
Conservative	10	63
Primary repair	6	38
Laryngeal Injury (n=13)		
Primary repair with temporary tracheostomy	9	69
Primary repair with endotracheal tube	2	15
Primary repair with permanent tracheostomy	1	8
Conservative	1	8
Tracheal Injury (n=5)		
Primary repair with endotracheal tube	3	60
Conservative	2	40
Esophageal Injury (n=3)		
Primary repair	3	100

Table 5. Complications and Outcomes

Outcome	Frequency (n)	Percent (%)
Airway Injury Complications		
Infection	4	13
Neck contracture	2	7
Stenosis	1	3
Digestive Injury Complications		
Infection	5	17
Fistula	3	10
Disruption of repair	1	3
Length of Hospital Stay		
< 2 weeks	11	37
2–4 weeks	11	37
>4 weeks	8	27
Patient Outcomes		
Survived without morbidity	20	67
Survived with morbidity	9	30
Mortality	1	3

be missed.

Furthermore, because this **single-center study** was conducted at a military hospital, the findings may not be generalizable to other facilities or conflict zones with differing resources and patient populations. The **lack of long-term follow-up** restricts insights into chronic morbidity, such as dysphagia or voice impairment, which are crucial for a complete understanding of patient recovery beyond acute survival. Finally, a potential **selection bias** exists, as the inclusion of patients who survived initial resuscitation and hospital admission might skew survival rates upward compared with an all-comers cohort.

These limitations underscore the need for future prospective multicenter studies with larger sample sizes to enhance generalizability and statistical robustness and to allow for comprehensive long-term outcome assessment in this challenging patient population.

The findings of this study have significant implications in the management of penetrating neck trauma with aerodigestive injuries, particularly in conflict zones and resource-limited settings. Our results highlight the need to develop and implement context-specific trauma management protocols. Given the high infection rates observed, a primary focus should be on **standardized antibiotic prophylaxis regimens** tailored to local resistance patterns and resource availability, alongside enhanced infection control measures, including rigorous wound care training for surgical staff.

Furthermore, the importance of **pre-hospital training** for medics and first responders cannot be overstated. Enhancing skills in early airway assessment and stabilization, as recommended by Simpson et al. [6], can be lifesaving. Concurrently, investment in **portable and low-cost diagnostic tools**, such as handheld ultrasound or basic endoscopy, where feasible, is crucial for improving the accuracy and timeliness of aerodigestive injury detection, particularly when advanced imaging such as CTA is not consistently available or practical because of resource constraints.

Finally, establishing or strengthening **regional trauma networks** may be beneficial. As proposed by Burgess et al. [9], such networks can help to centralize expertise, streamline referral pathways for complex cases, and facilitate shared learning and resource allocation. The integration of **telemedicine**, as suggested by Nowicki et al. [14], also holds promise for enhancing prehospital triage, providing remote expert consultation, and assisting surgical planning in resource-limited conflict settings. Ultimately, prospective multicenter studies are essential to validate these proposed strategies, refine the management algorithms, and assess the long-term outcomes of complex injuries.

CONCLUSION

This study highlights the effective management of aerodigestive injuries in penetrating neck trauma at a military hospital in Sana'a, Yemen, achieving a 97% survival rate in a resource-limited conflict setting despite resource constraints. Prompt prehospital care, multidisciplinary intervention, and selective management based on clinical and imaging findings are critical for improving these outcomes. However, high infection rates (13–17%) underscore the need for standardized antibiotic prophylaxis and enhanced infection control measures. We recommend the development of context-specific trauma protocols for conflict zones, prioritization of portable diagnostics, and training of prehospital providers in airway stabilization. Prospective multicenter studies are needed to refine management algorithms and improve long-term outcomes for these complex injuries.

LIST OF ABBREVIATIONS

CTA: Computed Tomography Angiography
ISS: Injury Severity Score
PNI: Penetrating Neck Injury
SPSS: Statistical Package for the Social Sciences
IQR: Interquartile Range

DECLARATIONS

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of the General Military Hospital in Sana'a, Yemen. As this was a retrospective study, the requirement for informed consent was waived by the ethics committee. This study complied with the Declaration of Helsinki, and patient confidentiality was maintained through anonymized data handling.

Consent for Publication

Not applicable, as no identifiable patient data were included in this study.

Availability of Data and Materials

The datasets analyzed in this study are available from the corresponding author upon reasonable request and are subject to ethical and institutional approval.

Competing Interests

The authors declare no competing financial or non-financial interests.

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Authors' Contributions

SAA, AAB, and NA contributed to the data collection and drafted the initial manuscript. YAO and HMJ designed the study, performed data analysis, and critically revised the manuscript. All the authors have reviewed and approved the final manuscript.

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