Cervical spine immobilization in penetrating cervical trauma is associated with an increased risk of indirect central neurological injury

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Abstract

This study hypothesized that cervical spine immobilization (CSI) in penetrating cervical trauma is associated with increased central neurologic injury rather than prevention. Data abstraction proceeded from a previously constructed patient database formed via retrospective chart analysis of the trauma registries of two independent American College of Surgeons verified Level 1 Trauma centers. Neurologic injuries were categorized as peripheral or central. Central neurologic injuries were further subdivided into spinal cord and brain injuries. Patients were grouped according to the presence and type of neurologic injury, the presence and type of cervical spine fracture, death, and the presence or absence of respiratory and vascular injury. Vascular injury was further subdivided into major and minor categories. Groups were compared statistically. Significance was accepted for p<0.05. Cervical spine fracture (CSFx) was a significant risk factor for cervical spinal cord injury (CSCI) (p=0.00001; RR 20.56; 95% CI 8.44-26.47) but all patients with unstable CSFx presented with complete spinal neurologic devastation. Major vascular injury was associated with brain injury (p=0.01; RR 10.21; 95% CI 6.67-15.65) but was not associated with CSCI (p=0.99) or CSFx (p=0.67). Hypoperfusion was a strong independent risk factor for cervical spinal cord injury (p=0.00001; RR 38.4; 95% CI 16.17-91.2). CSI was a significant risk factor for indirect central neurologic injury (p=0.001; RR 1.63; 95% CI 1.23-1.95). Brain injury was not associated with CSFx (p=0.35) or CSCI (p=0.08). No benefit of CSI in penetrating cervical trauma could be determined from this study. CSI entailed an absolute risk increase for central neurologic injury of 18.69% with a 5.3 number needed to harm (NNH).

Introduction

Current recommendations for CSI were developed for blunt trauma patients and empirically extended to include patients with penetrating injury [1–4]. CSI was designed to prevent progression of direct neurologic injury from cervical spine instability caused by CSFx and/or ligamentous injury. Cervical spine instability resulting from isolated ligamentous instability does not occur following penetrating cervical trauma making CSI unindicated in the absence of unstable CSFx. Unstable CSFx in association with neurologic salvageability has not been clearly shown to exist in the setting of unstable cervical spine fracture, death, and the presence or absence of respiratory and vascular injury. Vascular injury was further subdivided into major and minor categories. Groups were compared statistically. Significance was accepted for p<0.05. Cervical spine fracture (CSFx) was a significant risk factor for cervical spinal cord injury (CSCI) (p=0.00001; RR 20.56; 95% CI 8.44-26.47) but all patients with unstable CSFx presented with complete spinal neurologic devastation. Major vascular injury was associated with brain injury (p=0.01; RR 10.21; 95% CI 6.67-15.65) but was not associated with CSCI (p=0.99) or CSFx (p=0.67). Hypoperfusion was a strong independent risk factor for cervical spinal cord injury (p=0.00001; RR 38.4; 95% CI 16.17-91.2). CSI was a significant risk factor for indirect central neurologic injury (p=0.001; RR 1.63; 95% CI 1.23-1.95). Brain injury was not associated with CSFx (p=0.35) or CSCI (p=0.08). No benefit of CSI in penetrating cervical trauma could be determined from this study. CSI entailed an absolute risk increase for central neurologic injury of 18.69% with a 5.3 number needed to harm (NNH).

Empirc extension of CSI to penetrating cervical trauma occurred without rigorous examination of efficacy or cost-benefit analysis and inappropriate CSI is not without adverse effects. CSI can impede medical care of vascular and respiratory injuries in cases of penetrating cervical trauma [3,5,6] which raises concern given that penetrating cervical trauma causes major vascular injury in over 25% of patient with an incurred 50% mortality [1,6–9]. Central neurologic injury frequently results from compression of cerebral structures due to direct mechanical compromise (rapidly expanding hematomas) as well as impeding successful endotracheal intubation [6,14–16] potentially leading to hypoxia and further neurologic injury.

The rapid mortality associated with vascular and airway injuries emphasizes the importance of immediately treating these life-threatening injuries before addressing concerns about cervical spine instability [5,17–22]. Transport delays for CSI vary from an average of 8-30 mins [23,24]. Average total field times are reduced 34% from 46-20 mins by initiation of a "scoop and run" policy [24]. The effect of time on patient outcome is critical as a 10% increase in mortality accompanies every incremental 10 min delay in reaching definitive care. Expedited definitive care is needed not only for prevention of neurologic injury [11–13] but also because exsanguination is the cause of over 50% of deaths with penetrating cervical trauma [8]. Delayed operative repair of carotid injuries results in significant progression of cerebral neurologic sequelae [10,11]. CSI can cause respiratory compromise through direct mechanical compromise (rapidly expanding hematomas) as well as impeding successful endotracheal intubation [6,14–16] potentially leading to hypoxia and further neurologic injury.

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The time required for appropriate CSI may contribute to delay iatrogenia.

The purpose of this study is to examine the relationship between penetrating cervical trauma and the development of central neurologic injury with prophylactic CSI. The lack of applicability of CSI in penetrating cervical trauma and the host of iatrogenia associated injury with prophylactic CSI. The lack of applicability of CSI in penetrating cervical trauma and the development of central neurologic injury in penetrating cervical trauma is more likely associated with, rather than prevented by, CSI.

**Materials and methods**

Multi-center, retrospective chart analysis performed using the data housed in the trauma registries of two independent American College of Surgeons verified, Level 1 Trauma centers was used to construct a patient database [26,27]. The trauma registries of the Louisiana State University Health Sciences Center, New Orleans (New Orleans, LA-Charity) and the Hurley Medical Center, Flint, Michigan, were queried for all cases of penetrating cervical trauma. The Charity Hospital trauma registry was searched from 01/01/1994 to 04/17/2003, The Hurley Medical Center trauma registry was searched from 01/01/2000 to 12/31/2005. Charts were excluded for lack of penetrating cervical trauma, incompleteness and patient elopements prior to evaluation and patient discharges “against medical advice”. Patients were grouped according to the presence or absence of neurologic injury, CSFx, vascular injury, respiratory injury and CSI. Abstracted data included age, sex, race, mechanism of injury, admission Glasgow Coma Scale (GCS), admission neurologic findings, zone of injury, associated injuries, the types and findings on radiographic imaging, surgical intervention, neurologic outcome, disposition from the hospital and mortality. Institutional review board approval was obtained from Tulane University (New Orleans, LA), Louisiana State University Health Sciences Center, New Orleans, and Hurley Medical Center.

**Hospital systems**

Trauma surgery, orthopedic spine and neurological coverage at Charity were the responsibility of both Tulane University (Tulane) and Louisiana State University, New Orleans (LSU) and alternated daily between these two institutions. Senior radiology residents and staff radiologists of the LSU department of radiology provided radiology services. Emergency medicine coverage was continuously provided by LSU emergency medicine staff and residents. Hurley has teaching affiliations with Henry Ford Hospital (Detroit, MI), Michigan State University (Lansing, MI) and University of Michigan (Ann Arbor, MI). Radiology services were provided by Hurley radiology residents and staff radiologists. Emergency medicine staff and residents of University of Michigan provided continuous emergency medicine coverage.

Treatment of cervical spine injuries was similar between the treating institutions in that cervical spine injury associated with neurologic injury was care for by neurosurgery while all other cervical spine injury was cared for by orthopedics. Cervical instability was designed based on the three-column system [28]. Two of the three columns had to be disrupted to meet criteria for instability. Radiology provided initial reports of instability, which was then subject to confirmation by the consulting spine service. Peripheral nerve injury was defined as any neurologic injury attributable to the cervical distribution that was not related to a spinal cord injury. Spinal cord injury was defined as any injury of the spinal cord. CSFx induced any bony disruption of the cervical spinal column. Brain injury was defined as penetrating cervical trauma causing any indirect injury of the cerebral hemispheres, basal ganglia, cerebellum or brain stem structures. Direct penetrating brain injury was excluded from causal analysis.

Major vascular injury was defined as involving the internal jugular vein (IJV), common carotid artery (CCA), ICA, external carotid artery (ECA) and vertebral artery (VA). Minor vascular injuries were defined as any cervical vascular injury not considered a major vascular injury and included the external jugular vein (EJV), anterior jugular vein (AJV), occipital artery, lingual artery, thyroid artery, facial vein and unnamed veins.

**Data management and statistical analysis**

Patient data were recorded, described statistically, and presented in frequency and proportion using inherent database computational software (Microsoft Excel 2000, Redmond, WA). Tests for comparing the proportion difference between two conditions were conducted by Chi-squared (χ²) statistic using SAS v9.1 (SAS Institute Inc., Cary, NC). Significance was accepted for p < 0.05.

**Results**

The study cohort consisted of 231 patients. 35 of these patients died. All patient deaths were in the Charity group. Survivors numbered 153 patients in the Charity group and 43 in the Hurley group. Patient characteristics were summarized for both groups and statistically compared (Table 1). Demographics, mechanism of injury and neurologic deficits were similar between the two groups, but mortality and the incidence of CSI in the Charity group was significantly higher than the Hurley group.

Of 94 non-DOA patients with CSI, 15 (16%) had CSFx. All of these patients received CSI. Cervical spinal cord injury (CSCI) occurred in 8 (8.5%) non-DOA patients and 88% (7) had an associated CSFx. Two patients incurred unstable CSFx and both had attendant complete spinal cord neurologic devastation. CSFx was a significant risk factor for CSCI (p<0.00001; RR 20.56; 95% CI 5.21-32.33). However, unstable CSFx was associated with non-neurologic salvageability (p<0.0001; OR 0.001; 95% 0.00-0.05). 21 patients incurred 26 major vascular injuries (Table 2a). Multiple major vascular injuries occurred in five patients with accompanied minor vascular injury in three patients (Table 2b). The IJV was the most commonly injured major vessel (N=10) followed by unnamed veins.

| Table 1. Patient characteristics were summarized and compared statistically. |
|----------------------|--------|--------|-------|
| Demographic Characteristic | Charity | Hurley | Significance (p) |
| Male | 130 (84.96%) | 40 (93.02%) | NS |
| Female | 23 (15.03%) | 3 (6.98%) | NS |
| Age, mean ± SD, yrs | 28.97 ± 11.53 | 29.61 ± 11.64 | NS |
| African American | 111 (72.53%) | 31 (72.09%) | NS |
| Caucasian | 37 (24.18%) | 10 (22.26%) | NS |
| Other Race | 5 (3.27%) | 2 (4.65%) | NS |
| Other Race | 35 | 0 | 0.001 |
| Gunshot Wound | 59 (38.56%) | 21 (48.84%) | NS |
| Stab Wound | 94 (61.44%) | 22 (51.16%) | NS |
| Cervical Spine Fracture | 10 (6.54%) | 5 (11.63%) | NS |
| Brain Injury | 1 (0.65%) | 1 (2.33%) | NS |
| Respiratory Injury | 9 (5.88%) | 5 (11.63%) | NS |
| Peripheral Nerve Injury | 9 (5.88%) | 3 (6.98%) | NS |
| Cervical Spinal Cord Injury | 5 (3.27%) | 3 (6.98%) | NS |
| C-Spine Immobilization | 84 (54.90%) | 11 (25.58%) | < 0.001 |

The Charity and Hurley patient cohorts differed significantly only in the incidence of death and cervical spine immobilization (c-spine immobilization) Significance was accepted for p < 0.05
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Table 2a. Major vascular injuries indicating respective treating institutions and associated injuries.

| Major Vascular Injury | Charity | Hurley | PNI | CSCI | Brain Injury | CSF | CSI |
|-----------------------|---------|--------|-----|------|--------------|-----|-----|
| Internal Jugular Vein (IJV) | (+ICA)X | YES (XII) | No | No | No | No | No |
| 1 (+ICA)X | No | No | No | No | YES |
| 1 No | No | No | No | No | YES |
| 2 No | No | No | No | Yes | No |
| 2 No | No | No | No | No | 2 No |
| 1 (+VA)£ | YES (Brachial Plexus) | No | No | No | YES |
| 1 (+CCA)µ | No | YES (C6-7) | R MCA CVA | STABLE | YES |
| 1 No | No | No | No | No | YES |
| Common Carotid Artery (CCA) | 1 | No | No | No | No | Yes |
| 1 (+ICA)µ | YES (VII) | No | No | No | Yes |
| 1 No | No | No | No | Yes |
| 1 (+V A)£ | No | No | No | No | YES |
| 1 No | No | No | No | No | Yes |
| 1 (+ IJV)¥ | YES (XII) | No | No | No | Yes |
| 1 (+ ECA)€ | No | No | No | No | Yes |
| Internal Carotid Artery (ICA) | 1 (+CCA)µ | YES (VII) | No | No | No | Yes |
| 1 (+IJV)¥ | YES (XII) | No | No | No | No |
| 1 No | No | No | No | No |
| 1 (+ ECA)€ | No | No | No | No | Yes |
| External Carotid Artery (ECA) | 1 No | No | No | No | No |
| 1 (+CCA)µ | No | No | No | No | No |
| 1 (+VA)£ | No | No | No | No | No |
| Vertebral Artery (VA) | 1 (+CCA)µ | YES (VII/XII) | No | No | No | No |
| 1 No | No | No | No | No |
| 1 No | No | No | No | No |
| 1 (+VA)£ | NO | NO | NO | NO | No |
| 1 (+ICA)µ | YES (VII/XII) | No | No | No | No |
| 1 No | No | No | No | No |
| Minor Vascular Injury | Charity | Hurley | PNI | CSCI | Brain Injury | CSFx | CSI |
| Vertebral Artery (VA) | BILATERAL | No | QUADRIPLEGIA | No | UNSTABLE | C6 | YES |
| 1 (+ ECA)€ | No | No | No | No | Yes |
| 1 (+ IJV)¥ | YES (Brachial Plexus) | No | No | No | Yes |
| 1 (+ VA)£ | No | No | No | No | Yes |
| Anterior Jugular Vein (AJV) | 3 No | x 3 | No | x 3 | No | x 3 | Yes | x 3 |
| 3 No | x 3 | No | x 3 | No | x 3 | No | x 3 | Yes | x 3 |
| 1 (+ RV)€ | No | No | No | No | No |
| External Jugular Vein (EJV) | 2 No | x 2 | No | x 2 | No | x 2 | Yes | x 2 |
| 1 2 No | No | No | No | No |
| Minor Arteries (Occipital, Lingual, Thyroid) | 1 (Occipital) | No | No | No | No | Yes |
| 1 (Lingual) | No | No | No | No | No |
| 1 Superior Thyroid | No | No | No | No | No |
| 1 Superior Thyroid | No | No | No | No | No |
| 1 Lingual | No | No | No | No | No |
| Minor Veins (Facial, Unnamed) | 1 FV (+CCA)¶ | No | No | No | No | Yes |
| 4 Unnamed | No | x 4 | No | x 4 | No | x 4 | No | x 4 |
| 1 FV (+TCT)¶ | No | No | No | No | No |
| Non-Cervical Vascular Injury | Thyrocervical Trunk (TCT) | 1 (+ FV)§ | No | No | No | No | No |
| Left Ventricle | 1 (+ AJV)¶ | No | No | No | No | No |
| Right Ventricle (RV) | 1 No | No | No | No | No |

PNI: Peripheral nerve; CSCI: Cervical spinal cord; CSFx: Brain and cervical spine fracture; CSI: Cervical spine immobilization, indicating presence on admission (YES) or absence on admission (No); VA: Vertebral Artery; FV: Facial Vein; AJV: Anterior jugular vein; C6: Cervical vertebra six; R MCA: Right middle cerebral artery; CVA: Cerebrovascular Accident.

Same superscripts indicate same patient

Table 2b. Minor vascular injuries indicating respective treating institutions and associated injuries.

| Minor Vascular Injury | Charity | Hurley | PNI | CSCI | Brain Injury | CSFx | CSI |
|-----------------------|---------|--------|-----|------|--------------|-----|-----|
| Vertebral Artery (VA) | BILATERAL | No | QUADRIPLEGIA | No | UNSTABLE | C6 | YES |
| 1 (+ ECA)€ | No | No | No | No | Yes |
| 1 (+ IJV)¥ | YES (Brachial Plexus) | No | No | No | Yes |
| 1 (+ VA)£ | No | No | No | No | Yes |
| Anterior Jugular Vein (AJV) | 3 No | x 3 | No | x 3 | No | x 3 | Yes | x 3 |
| 3 No | x 3 | No | x 3 | No | x 3 | No | x 3 | Yes | x 3 |
| 1 (+ RV)€ | No | No | No | No | No |
| External Jugular Vein (EJV) | 2 No | x 2 | No | x 2 | No | x 2 | Yes | x 2 |
| 1 2 No | No | No | No | No |
| Minor Arteries (Occipital, Lingual, Thyroid) | 1 (Occipital) | No | No | No | No | Yes |
| 1 (Lingual) | No | No | No | No | No |
| 1 Superior Thyroid | No | No | No | No | No |
| 1 Superior Thyroid | No | No | No | No | No |
| 1 Lingual | No | No | No | No | No |
| Minor Veins (Facial, Unnamed) | 1 FV (+CCA)¶ | No | No | No | No | Yes |
| 4 Unnamed | No | x 4 | No | x 4 | No | x 4 | No | x 4 |
| 1 FV (+TCT)¶ | No | No | No | No | No |
| Non-Cervical Vascular Injury | Thyrocervical Trunk (TCT) | 1 (+ FV)§ | No | No | No | No | No |
| Left Ventricle | 1 (+ AJV)¶ | No | No | No | No | No |
| Right Ventricle (RV) | 1 No | No | No | No | No |

PNI: Peripheral nerve; CSCI: Cervical spinal cord; CSFx: Brain and cervical spine fracture; CSI: Cervical spine immobilization, indicating presence on admission (YES) or absence on admission (No); ECA: External Carotid Artery; IJV: Internal jugular vein; FV: Facial Vein; CCA: Common carotid artery; AJV: Anterior jugular vein; C6: Cervical vertebra six; R MCA: Right middle cerebral artery; CVA: Cerebrovascular Accident.

Same superscripts indicate same patient
Cervical spine immobilization in penetrating cervical trauma is associated with an increased risk of indirect central neurological injury. Prehospital death, or DOA, was pronounced in seven patients. CSI was performed in six of the DOA patients. CSI was performed in 13 of the 18 early decedents, and in eight of the ten late decedents (Table 5). Cardiac arrest was the most common cause of death in the early group indicating exsanguination and/or hypoxia as the cause of death. Death from traumatic cardiac arrest was considered penultimate indirect neurologic injury. Direct CSI occurred in six patients (Table 3). All of these patients received CSI. Patients with direct brain injury were excluded.

14 patients presented with 16 airway injuries (Table 4). Six of these patients received CSI of which two had compound airway injuries. Two patients underwent emergent cricothyroidotomy upon arrival and one of these patients arrived in CSI. 12 patients (6%) presented with 17 peripheral nerve injuries (PNI) (Table 6). Respiratory injury was associated with PNI (p=0.04; RR 4.33; 95% CI 1.32-14.22) but not CSFx (0.61), C5 (0.79), major vascular injury (0.22) or central neurologic injury (0.99).

Brain injury occurred in two patients, one with a CSFx and one without. Brain injury was neither associated with CSFx (p=0.35) nor CSI (p=0.08). Hypoperfusion occurred in four patients and was a significant risk factor for indirect central neurologic injury (p<0.0001; RR 38.4; 95% CI 16.17-91.2). Statistical comparisons were summarized on Table 7.

Discussion
Central neurologic injury with penetrating cervical trauma was more likely associated with, rather than prevented by, CSI in this study. This study constituted the first known neurologic risk/benefit analysis of CSI. CSI in this study demonstrated a significant increase in indirect neurologic injury without any possibility of prophylaxis against progression of indirect neurologic injury from unstable CSFx. The juxtaposed non-incidence of salvageable direct CSI amenable to CSI prophylaxis with the marked incidence of treatable vascular trauma and shock (combined incidence vascular trauma and shock %). Appeared a likely source of this increased risk of indirect central neurologic injury. CSI iatrogenia may have facilitated indirect neurologic injury by negatively impacting the "ischemic penumbra" [2-6,15,22-24,27,29,30].

Two cases of unstable CSFx were found in this study which was 1% of all patients. Both of these patients had associated complete neurologic devastation which made prophylactic CSI inappropriate. The true incidence of indicated CSI in this study then was 0%. Four patients in this study developed indirect central neurologic injury.

Prehospital mortality was defined as death prior to arrival in the emergency department and also termed dead on arrival (DOA). Early death was defined as death following arrival in the emergency department but prior to being admitted to the hospital. Late date was defined as in hospital death excluding early and prehospital deaths.

Table 3. Cervical Spinal Cord Injuries indicating the Number of Patients at Each Institution, the Mechanism of Injury (Direct versus Indirect) and the Presence or Absence of Cervical Spinal Immobilization.

| CERVICAL SPINAL CORD INJURIES | CHARITY HURLEY INJURY CSI |
|--------------------------------|--------------------------|
| Complete                        | 2                        |
| C2 Quadriplegia                 | Direct Yes               |
| C5 Quadriplegia                 | Direct Yes               |
| C6 Quadriplegia                 | Direct Yes               |
| Incomplete                      | 4                        |
| C8 Paraplegia                  | Direct Yes               |
| C6 Temporary Quadriplegia       | Direct Yes               |
| C6 Contusion                    | Direct Yes               |
| C3 Central Cord Syndrome        | Indirect No              |
| C5 Central Cord Syndrome        | Indirect Yes             |
| TOTAL                           | 5                        |

Table 4. Classification of Indirect Central Neurologic Injuries as Brain or Cervical Spinal Cord with Mechanism of Injury.

| Indirect Central Neurologic Injuries | Number of Patients | Mechanism | CSI |
|-------------------------------------|--------------------|-----------|-----|
| Brain Injuries                      | 2                  |           |     |
| R CVA                               | 1                  | SW R ICA  | YES |
| R CVA                               | 1                  | GSW R CCA | YES |
| Cervical Spinal Cord Injury         | 2                  |           |     |
| Central Cord Syndrome               | 1                  | Shock     | YES |
| Central Cord Syndrome               | 1                  | Shock     | NO  |

GSW: Gunshot Wound; SW: Stab Wound; R: Right; ICA: Internal Carotid Artery; CCA: Common Carotid Artery; CVA: Cerebrovascular Accident

Table 5. Patient fatalities categorized according to time position of post–injury occurrence with noted presence (+CSI) or absence (-CSI) of cervical spine immobilization (CSI).

| PATIENT FATALITIES                     | +CSI | -CSI |
|----------------------------------------|------|------|
| TIME OF DEATH                          |      |      |
| Dead on Arrival (Prehospital)          | 6    | 1    |
| Emergency Department Deaths (Early)    | 13   | 5    |
| Cardiac Arrest                         | 11   | 4    |
| Exsanguination                         | 1    | 1    |
| Traumatic Brain Injury                 | 1    | 0    |
| Died in Hospital (Late)                | 8    | 2    |
| Cardiac Arrest in OR                   | 3    | 1    |
| Anoxic Brain Injury                    | 2    | 0    |
| Multi-System Organ Failure             | 2    | 0    |
| Right Cerebral Infarct                 | 1    | 0    |
| Traumatic Brain Injury                 | 0    | 1    |
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Table 6. Respiratory tract injuries indicating respective treatment institutions and associated injuries.

| Respiratory Tract Injury | Charity | Hurley | PNI | CSCI | CSFx | Vascular Injury | CSI |
|--------------------------|---------|--------|-----|------|------|----------------|-----|
| Trachea                  | 1       | No     | No  | No   | No   | No             | No  |
|                          | 1       | No     | No  | No   | No   | Yes            | No  |
|                          | 1       | YES (Laryngeal) | No | No   | No   | Yes            | No  |
|                          | 1       | YES (Laryngeal) | No | No   | No   | Yes            | No  |
| Pharynx                  | 1 (+ Hypopharynx) | No | No  | No  | No   | Yes            | No  |
|                          | 1       | No     | No  | No   | Yes (ECA) | Yes           | No  |
|                          | 1       | No     | No  | No   | No   | Yes (ECA)      | Yes |
|                          | 1       | No     | No  | No   | No   | No             | No  |
| Hypopharynx              | 1 (+ Pharynx) | No | No  | No  | No   | Yes            | No  |
|                          | 1 (+ Larynx) | No | No  | No  | Yes (ECA) | Yes           | No  |
|                          | 1       | No     | No  | No   | Yes (ECA) | Yes           | No  |
| Larynx                   | 1       | YES (Brachial Plexus) | No | No   | No   | Yes            | No  |
|                          | 1 (+ Hypopharynx) | No | No  | No  | No   | Yes (IJV)      | No  |

PNI: Peripheral nerve; CSCI: Cervical spinal cord; CSFx: Brain and cervical spine fracture; CSI: Cervical spine immobilization, indicating presence on admission (YES) or absence on admission (No); ECA: External Carotid Artery; CCA: Common Carotid Artery; IJV: Internal Jugular Vein

Same superscript indicates same patient

Table 7. Conditional Risks. CSCI – Cervical Spinal Cord Injury.

| Clinical Condition                  | p     | Relative Risk | 95% Confidence Interval |
|-------------------------------------|-------|---------------|-------------------------|
| Brain Injury v. CSCI                | NS    | N/A           | N/A                     |
| Brain Injury v. CSFx                | NS    | N/A           | N/A                     |
| Indirect Cent Neuro Inj v. Hypoperfusion | < 0.00001 | 38.40          | 16.17 – 91.20          |
| CSCI v. CSFx                        | < 0.00001 | 20.56          | 8.44 – 26.47           |
| CSCI v. Unstable CSFx               | 0.001 | 32.33          | 5.21 – 32.33           |
| Major VI v. Brain Injury            | 0.01  | 10.21          | 6.67 – 15.65           |
| Major VI v. CSCI                    | NS    | N/A           | N/A                     |
| Major VI v. PNI                     | NS    | N/A           | N/A                     |
| Major VI v. CSFx                    | NS    | N/A           | N/A                     |
| Major VI v. CSI                     | NS    | N/A           | N/A                     |
| CSI v. Indirect Cent Neuro Inj      | < 0.001 | 1.635          | 1.23 – 1.95            |
| Respiratory Injury v. Brain Injury  | NS    | N/A           | N/A                     |
| Respiratory Injury v. CSI           | NS    | N/A           | N/A                     |
| Respiratory Injury v. CSFx          | NS    | N/A           | N/A                     |
| Respiratory Injury v. PNI           | 0.04  | 4.33           | 1.32 – 14.22           |
| Respiratory Injury v. Major VI      | NS    | N/A           | N/A                     |

VI: Vascular Injury; CSFx: Cervical Spine Fracture; CSI: Cervical Spine Immobilization; Indirect Cent Neuro Inj: Indirect Central Neurologic Injury; PNI: Peripheral Nerve Injury

Significance was accepted for indirect neurologic injury (p<0.001; RR 1.635; 95% CI 1.23–1.95).

Direct CSI occurred in 3.1% of all surviving patients. Major vascular injury occurred in 11% of surviving patients which constituted a nearly 3.5-fold greater incidence than direct CSI. Prior studies reported major vascular injury complicating over 25% of penetrating cervical trauma [1,7-9,17]. The source of discrepancy between the incidence of major vascular injury in this study and other reported studies was not clear but may represent statistical variance. Alternatively, this percentage difference may reflect inclusion loss secondary to death in the study cohort. All deaths in this study occurred in Charity patients wherein CSI was regularly practiced as opposed to Hurley patients where in CSI was restricted. Prior analysis of the Charity cohort (Vanderlan) reported vascular and respiratory compromise as the likely source of fatality. The incidence of vascular injury with penetrating cervical trauma when all 35 fatalities were added to the number of survivors with known vascular injury (21+35=56/196+35). The incidence also more closely approximated the prior reported incidence if patients that were excluded as early and late deaths were included with the known vascular injury survivors.
The reported incidence of direct neurologic injury in penetrating cervical trauma ranges from <1%-7% [1,3,9,40]. Direct CSCI was noted in 3.06% of surviving patients in this study and found agreement with the prior reported incidence range. The incidence of direct CSCI with unstable CSFx in this study was 1%. Rhee, et al., reported in a large meta-analysis that concurrent CSFx and CSCI with penetrating cervical trauma was an extremely rare event with an incidence of less than 0.6% [3]. Lustenberger, et al., recently reported a similar incidence of concurrent CSFx and CSCI at 0.4% for penetrating cervical trauma and specifically noted this concurrence is commensurate with severe neurologic impairment with no benefit recognized from surgical stabilization [41]. The slightly greater incidence of CSCI and unstable CSFx in this study compared to those cited was unclear but may be isolated statistical variance. The incidence of CSCI and unstable CSFx in this study however, agrees with prior studies that no neurologic salvageability noted in the study cohort [42,43].

Possible benefit from deferring CSI in this study greatly exceeded the less than 1% possibility of benefit since none of the 94 (48% of all patients) of surviving patients who received CSI with an associated unstable CSFx were neurologically salvageable. While none of these 94 patients may have benefitted from CSI, 100% of them were exposed to the risk of CSI iatrogenia. Deferring CSI might have especially benefitted the 15% of patients in this study that were critically injured for whom undelayed transport to definitive care was most important[35]. The importance of deferring CSI in these severely injured patients became clear when recognizing that CSI under ideal conditions, and excluding errors, required approximately 6 mins while a 10% increase in mortality was associated with each ten-min delay in reaching definitive care [23,25]. These patients were then viewed as unsalvageable. Early and late deaths were included in the analysis of indirect neurologic injury because the cause of death in this cohort was previously determined as exsanguination and/or hypoxia [27]. Justification for inclusion of early and late deaths rested on the theory that within the ischemic penumbra there is some point on the continuum of injury where irreversible indirect neurologic injury occurs and the ischemic penumbra loses all salvageability.

DOA patients were excluded from analysis because cardiopulmonary resuscitation was not associated with CSI in this patient cohort, indicating possible rapid prehospital death [27]. Prehospital death from penetrating cervical trauma may have resulted from severe hemorrhage, respiratory injury, neurologic injury or a combination of these. Autopsy results were not available for patients in the DOA category so these patients were excluded from the analysis.

Respiratory tract injuries have been reported in up to 20% of penetrating neck injuries with a maximum mortality of 33% [1,7,17]. Respiratory physiology and obtaining of a definitive airway had both been previously shown to be impaired by CSI [2,6,15,16]. Consideration was then given to examining the relationship between respiratory tract injuries and indirect neurologic injury in this study. This incidence of respiratory tract injuries in this study was 7.1%. CSI was performed in six patients with respiratory injuries of which two had commensurate major vascular injuries. The association between respiratory injury, major vascular injury and CSI was insignificant. CSFx did not occur in any patient with respiratory tract injuries. Respiratory tract injury was also not associated with central neurologic injury. Peripheral neurologic injury was a significant risk for respiratory tract injury (p=0.04; RR 4.33; 95% CI 1.32-14.22) which seemed consistent with cervical anatomy.

Calculating the effectiveness of CSI in penetrating cervical trauma could not be determined in this study because unstable CSFx did not occur in any patients with neurologic salvageability. The absence of cervical instability occurring with neurologic salvageability in this...
study was predictable from the surveyed literature and may reflect an incidence so remote as to be undiscoverable. Only one case of cervical spine instability resulting from penetrating cervical trauma in a neurologically intact patient has been reported and the accuracy of this report has been challenged (Vanderlan) [20]. Interestingly, the patient’s cervical collar was removed in transit for control of hemorrhage without resultant central neurologic injury [20]. With only a single case report of a neurologically intact patient with cervical spine instability secondary to penetrating cervical trauma, the true number needed to treat (NNT) was hypothesized to lie between zero and negative infinity (0>NNT>−∞). The probability of the NNT being negative seemed even more likely given that this sole case entailed discontinuation of CSI without subsequent neurologic consequence. The absolute risk increase for central neurologic injury associated with CSI was 18.69% in this study, paired with a NNH of 5.3.

Haut et al. [30] retrospectively reviewed the National Trauma Data Bank and calculated the NNT and NNH for CSI in penetrating cervical trauma [30]. Possible benefit was defined “as patients with incomplete spinal cord injury that underwent operative repair”. This definition permitted NNT and NNH calculations but provided an inaccurate assessment of CSI effectiveness because (1) CSI only benefits neurologically intact patients with unstable CSFs, (2) operative repair in penetrating cervical trauma does not constitute cervical spine instability, (3) cervical spine instability in penetrating cervical trauma usually results from necessary surgical iatrogenia, and (4) incomplete spinal cord injury had not been definitively proven to occur commensurately with cervical spine instability from penetrating cervical trauma.

The absence of cervical spine instability with commensurate neurologic salvageability and the resultant inability to accurately determine NNT were limitations of this study. This study was also limited by a relatively small sample size and by all the inherent problems of a retrospective study.

Conflicts of interest

The authors have no conflicts of interest.

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