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Case-controlled Study

# Utilization of computerized tomography and magnetic resonance imaging for diagnosis of traumatic C-Spine injuries at a level 1 trauma center: A retrospective Cohort analysis

Mason Sutherland [a], Mitchell Bourne [a], Mark McKenney [a,b], Adel Elkbuli [a,*]

[a] Department of Surgery, Division of Trauma and Surgical Critical Care, Kendall Regional Medical Center, Miami, FL, USA
[b] Department of Surgery, University of South Florida, Tampa, FL, USA

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ABSTRACT

*Background:* Computerized tomography (CT) is a common imaging modality for trauma patients, but there is debate regarding the role of magnetic resonance imaging (MRI) in cervical (C)-spine clearance. We aim to investigate the utilization of CT and MRI imaging in traumatic C-spine clearance and associated outcomes on patients who undergo both imaging modalities.

*Methods:* A 4-year retrospective review was performed to evaluate the trauma patient imaging algorithm at our institution. The algorithm required CT as a screening examination for traumatic injury patients who are unexaminable because of distracting injury, altered mental status, an abnormal neurological examination, and/or central neck pain. MRI was performed after CT in patients with C-spine injuries identified on CT, those who remained unexaminable, had an abnormal neurological examination, or experienced persistent central neck tenderness. Univariate analyses and adjusted multivariate logistic regression were performed with significance defined as $p < 0.05$.

*Results:* 805 patients were analyzed. Compared to MRI, CT had a sensitivity of 50.2%, specificity of 76.6%, positive predictive value of 69.7%, and negative predictive value of 59.0% in detecting C-spine injuries. CT and MRI differed significantly in their ability to detect C-spine soft tissue injuries and C1 vertebral fractures ($p < 0.05$).

*Conclusions:* MRI is more capable of detecting soft tissue injuries whereas CT is superior in detecting vertebral fractures. Our findings support the need to utilize CT and MRI in conjunction to detect both bony and soft tissue C-spine injuries in traumatically injured patients, who are either unexaminable, have an abnormal neurologic examination, or ongoing central neck tenderness.

## 1. Background

In the United States, the incidence of vertebral or soft tissue cervical spine (C-spine) injury after blunt traumatic injury is 2–6% [1,2]. As the sequelae of improperly identifying C-spine injuries are potentially catastrophic, the early diagnosis of these injuries is crucial to minimize trauma patient morbidity and mortality. Previous studies have concluded that computerized tomography (CT) outperforms plain radiography and serves as the best initial screening modality for C-spine injuries [3–5]. Although CT is sensitive in the detection of most clinically significant injuries, it may be unable to detect more subtle injuries to the spinal cord, such as central cord syndrome [5]. For this reason, the 2020 guidelines and algorithm put forward by the Western Trauma Association (WTA) recommend that trauma patients with an abnormal neurologic examination and negative CT findings undergo magnetic resonance imaging (MRI) [6].

However, the use of MRI in suspected C-spine injury patients remains controversial due to potential disadvantages including a low degree of utility and cost-effectiveness in the neurologically intact trauma patient [7–9]. Additionally, the time required to facilitate the use of MRI can subject unstable patients to risk of complications by delaying treatment and prolonging C-spine immobilization with a cervical collar (C-collar), the use of which has the capability to elevate intracranial pressure and cause secondary brain injury [10,11]. Furthermore, there is currently

* Corresponding author. Department of Surgery, Kendall Regional Medical Center, 11750 Bird Road. Miami, FL 33175, USA.
*E-mail address:* adel.elkbuli@hcahealthcare.com (A. Elkbuli).

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limited literature directly comparing the utility and predictive value of CT vs. MRI in the detection of cervical injuries at specific vertebral levels, as well as specific soft tissue injuries, in direct relation to patient outcomes. Therefore, this study aims to assess the utilization of CT and MRI in traumatic C-spine clearance and associated outcomes for the adult and geriatric trauma populations who were treated at our level 1 trauma center (TC), as well as to provide additional evidence-based recommendations for optimal and safe use of CT and MRI in trauma patients.

## 2. Methods

### 2.1. Study design & materials

A retrospective single-institution cohort study was performed utilizing data from the trauma registry of our American College of Surgeons Committee on Trauma (ACS-COT)-verified level 1 TC over 4 years, from 1/1/2013–12/31/2016. Radiological diagnoses were obtained via de-identified data of individual patient C-spine CT and MRI reports. Study inclusion criteria were the following: patients who suffered traumatic injury, were unexaminable (i.e. distracting injury or altered mental status), had abnormal neurologic findings on physical examination, or central neck tenderness and subsequently underwent both CT and MRI C-spine imaging. Study exclusion criteria were the following: adult patients who were transferred to our facility, patients with missing demographic or outcome measures information, and pediatric patients (age <18 years). This study was conducted in compliance with ethical principles, was reviewed by our institutional review board, and was deemed exempt.

### 2.2. Patient population & study groups

Patients satisfying our study inclusion and exclusion criteria were stratified by the following variables:

- Age (adult [age 18–64 years] vs. geriatric [age ≥ 65 years])
- Gender (male vs. female)
- Race (Native American, Asian American, Black/African American, White/Caucasian, Other Race)
- Presence or absence of traumatic brain injury (TBI) as determined by findings of hemorrhage on CT Brain imaging (with subdivisions for Glasgow Coma Scale [GCS] grading of 13–15 = mild, GCS 8–12 = moderate, GCS <8 = severe) [12]
- Injury severity score (ISS) (low [1-14], intermediate [15–24], severe [≥25]) [13]
- C-spine injuries (C1–C7 vertebral fracture, edema, ligamentous injury, hematoma, disc injury)
- Examinable or unexaminable according to WTA definitions (examinable = GCS 15, unexaminable = GCS ≤14) [6]

### 2.3. Outcome measures

#### 2.3.1. Primary outcome

Primary outcome measures were concordance rates and the sensitivity, specificity, negative predictive value (NPV), and positive predictive value (PPV) of CT compared to MRI for the following C-spine injuries: C1–C7 vertebral fracture, ligamentous injury, contusion, hematoma, and disc injury. Disc injuries were only included if the spine specialist determined the injury to be acute and consistent with patients' symptoms. If there was disagreement between CT and MRI findings, the neuro-spine specialist adjudicated.

#### 2.3.2. Secondary outcome

Secondary outcome measures were unadjusted and adjusted mortality rates when stratifying patients by C-spine injury, ISS, and emergency department length of stay (ED-LOS) while controlling for age, gender, race, ISS, comorbidities using Charleston Comorbidity Index (CCI), and with & without ED-LOS where one of these variables are not the outcome of interest.

### 2.4. Statistical analysis

Univariate analysis was utilized to summarize patient demographic and clinical variable information. Multivariate logistic regression was utilized in order to investigate unadjusted and adjusted mortality while controlling for age, gender, race, ED-LOS, and comorbidities using CCI. McNemar's Paired Test was utilized in order to determine concordance rates between MRI vs. CT for specified C-spine injuries. IBM SPSS Statistics Version 27.0 (Armonk, NY) was utilized for all statistical analyses with significance defined as $p < 0.05$. This study was reported in line with the STROCSS criteria [14]. This work was submitted to the Research registry (UIN #: researchregistry6858) which can be found via the following link (https://www.researchregistry.com/browse-the-registry#home/registrationdetails/60ad7378266be10020221734/):

## 3. Results

### 3.1. Patient demographics

Out of 10,454 trauma patients treated from 1/1/2013–12/31/2016, a total of 805 (7.7%) patients satisfied our inclusion/exclusion criteria and were analyzed. The median age of patients was 42 years, with a total of 500 (62.1%) males and 305 (37.9%) females (Table 1). White/Caucasian patients comprised the largest fraction of patients (548; 68.1%) (eTable 1). A median GCS of 15 and median CCI of 0 was observed for the whole patient cohort. A total of 17/805 patients died, producing an overall mortality rate of 2.1% (Table 1). Patient sub-analysis by ISS, TBI, injuries sustained, whether examinable or not, C-collar status, CCI and race are listed in eTables 2-6.

### 3.2. Primary outcomes

In comparison to MRI, CT had an overall sensitivity in detecting all C-spine injuries of 50.2%. The CT sensitivity for C1–C7 vertebral fracture was 85.4% and the sensitivity for C-spine soft tissue injuries was 43.1%. In comparison to MRI, the overall PPV of CT in detecting all C-spine injuries was 69.7%, the PPV for C1–C7 vertebral fracture was 86.8%, and the PPV for C-spine soft tissue injuries was 68.1% (Table 2, eTables 7-8).

In comparison to MRI, the overall specificity of CT in detecting all C-spine injuries was 76.6%, the specificity for C1–C7 vertebral fracture

**Table 1**
Demographic characteristics of study population.

| Age | |
|---|---|
| Median (years) | 42.0 |
| Geriatric | 171 (21.2%) |
| Adult | 634 (78.8%) |
| **Gender** | |
| Male | 500 (62.1%) |
| Female | 305 (37.9%) |
| **Race** | |
| White/Caucasian | 548 (68.1%) |
| Other Race | 174 (21.6%) |
| Black/African American | 75 (9.3%) |
| Asian | 5 (0.6%) |
| Native American | 3 (0.4%) |
| **Glasgow Coma Scale** | |
| Median | 15 |
| Mild TBI GCS 13–15 | 630 (78.3%) |
| Moderate TBI GCS 8–128 | 52 (6.4%) |
| Sever TBI GCS <8 | 123 (15.3%) |

Abbreviations: GCS = Glasgow Coma Scale; TBI = Traumatic Brain Injury.

**Table 2**
Sensitivity, Specificity, Positive Predictive Value, and Negative Predictive Value of CT Compared to MRI for vertebral fractures and soft tissue injuries.

| Injury | | Sensitivity | Specificity | PPV | NPV |
|---|---|---|---|---|---|
| **Vertebral Fracture** | C1 (n = 33) | 95.5% | 98.6% | 65.6% | 99.9% |
| | C2 (n = 72) | 83.3% | 98.4% | 80.7% | 98.7% |
| | C3 (n = 11) | 71.4% | 99.5% | 55.6% | 99.8% |
| | C4 (n = 22) | 70.6% | 99.4% | 70.6% | 99.4% |
| | C5 (n = 33) | 73.9% | 98.7% | 63.0% | 99.2% |
| | C6 (n = 48) | 68.4% | 98.7% | 72.2% | 98.4% |
| | C7 (n = 65) | 72.9% | 97.8% | 67.3% | 98.3% |
| **Soft Tissue Injury** | Edema (n = 47) | 0.0% | 99.9% | 0.0% | 93.0% |
| | Ligamentous Injury (n = 130) | 5.5% | 99.7% | 77.8% | 84.8% |
| | Contusion (n = 26) | 100.0% | 100.0% | 100.0% | 100.0% |
| | Hematoma (n = 23) | 6.3% | 99.1% | 12.5% | 98.1% |
| | Disc Injury (n = 124) | 6.1% | 98.7% | 46.7% | 86.3% |

Abbreviations: PPV = Positive Predictive Value, NPV = Negative Predictive Value.

was 96.1%, and the specificity for C-spine soft tissue injuries was 85.1%. In comparison to MRI, the overall NPV of CT in detecting all C-spine injuries was 59.0%, the NPV for C1–C7 vertebral fracture was 95.7%, and the NPV for C-spine soft tissue injuries was 67.1% (Table 2, eTables 7-8).

Among 156 patients with cervical vertebrae fractures detected on CT scan, it was found that CT did not detect 91 soft tissue injuries, which consisted of 44 cases of ligamentous injury, 27 cases of C-spine edema, 12 cases of disc injury, and 8 cases of hematoma that were detected on MRI, with no missed cases of contusion. Among 307 unexaminable patients, it was found that CT did not detect 108 soft tissue injuries, which consisted of 56 cases of ligamentous injury, 21 cases of C-spine edema, 28 cases of disc injury, and 3 cases of hematoma that were detected on MRI with no missed cases of contusion.

McNemar's paired proportion analysis revealed statistically significant differences in concordance rates between CT and MRI for the detection of any C-spine injury ($p < 0.001$), any C-spine soft tissue injury ($p < 0.001$), C1 vertebral fracture ($p = 0.006$), C-spine edema ($p < 0.001$), C-spine ligamentous injury ($p < 0.001$), and C-spine disc injury ($p < 0.001$) (Tables 3–5).

### 3.3. Secondary outcomes

The raw mortality rate for patients who sustained any C-spine injury was 2.6%, whereas patients without a C-spine injury had a raw mortality rate of 1.3%. Compared to patients with a low ISS, those with a severe ISS experienced over 12-fold higher adjusted odds of mortality without controlling for ED-LOS and 13-fold higher adjusted odds of mortality when controlling for ED-LOS (Table 6). Compared to examinable patients, unexaminable patients experienced over 6-fold higher odds of mortality without controlling for ED-LOS and 8-fold higher odds of mortality when controlling for ED-LOS (Table 6).

Raw mortality rates for patients with <1 h ED-LOS, 1–1.99 h ED-LOS, 2–3.99 h ED-LOS, 4–5.99 h ED-LOS, and ≥6 h ED-LOS were 0.0%, 3.4%, 1.9%, 1.1%, and 2.2%, respectively. Adjusted odds of mortality were not significantly different when comparing ED-LOS groups (Table 6).

## 4. Discussion

Although CT was found to be effective at ruling out vertebral fractures in patients, MRI was more sensitive in detecting C-spine soft tissue injuries overall. These results are supportive of WTA guidelines suggesting that negative findings on high-quality CT imaging are not adequate for C-spine clearance in patients with an abnormal neurological examination or central neck tenderness [5,6,15–17].

**Table 3**
Paired Proportion Analysis of CT vs. MRI for Cervical Spine Vertebral Fractures and Soft Tissue Injury.

| Injury | | | MRI+ | MRI- | p-value |
|---|---|---|---|---|---|
| Any C-Spine Injury | | CT+ | 209 | 91 | <0.001* |
| | | CT- | 207 | 298 | |
| **Vertebral Fracture** | C1 | **CT+** | 21 | 11 | 0.006* |
| | | **CT-** | 1 | 772 | |
| | C2 | **CT+** | 50 | 12 | 0.832 |
| | | **CT-** | 10 | 733 | |
| | C3 | **CT+** | 5 | 4 | 0.687 |
| | | **CT-** | 2 | 794 | |
| | C4 | **CT+** | 12 | 5 | 1.000 |
| | | **CT-** | 5 | 783 | |
| | C5 | **CT+** | 17 | 10 | 0.454 |
| | | **CT-** | 6 | 772 | |
| | C6 | **CT+** | 26 | 10 | 0.832 |
| | | **CT-** | 12 | 757 | |
| | C7 | **CT+** | 35 | 17 | 0.585 |
| | | **CT-** | 13 | 740 | |
| **Any Vertebral Fracture** | | **CT+** | 158 | 24 | 0.780 |
| | | **CT-** | 27 | 596 | |
| **Soft Tissue Injury** | Edema | **CT+** | 0 | 1 | <0.001* |
| | | **CT-** | 56 | 748 | |
| | Ligamentous Injury | **CT+** | 7 | 2 | <0.001* |
| | | **CT-** | 121 | 675 | |
| | Contusion | **CT+** | 26 | 0 | 1.000 |
| | | **CT-** | 0 | 779 | |
| | Hematoma | **CT+** | 1 | 7 | 0.134 |
| | | **CT-** | 15 | 782 | |
| | Disc Injury | **CT+** | 7 | 9 | <0.001* |
| | | **CT-** | 108 | 681 | |
| **Any Soft Tissue Injury** | | **CT+** | 147 | 69 | <0.001* |
| | | **CT-** | 194 | 395 | |

*Indicates statistical significance ($p < 0.05$).
Abbreviations: MRI = Magnetic Resonance Imaging, CT = Computerized Tomography.

Evidence-based clinical guidelines are necessary to help guide physicians through the evaluation and treatment of blunt traumatic injuries. Inaba et al. previously described WTA imaging practice guidelines for trauma patients with an uncleared C-spine and recommended that patients who did not fit the National Emergency X-Radiography Utilization Study (NEXUS) low-risk criteria should undergo CT [5]. Our findings that MRI was superior to CT in the detection of a subset of soft tissue injuries such as C-spine edema supports WTA conclusions that MRI is superior to CT in the detection of a small percentage of clinically significant injuries [17]. Additionally, our finding that CT did not detect 5.1–28.2% of soft tissue injuries detected by MRI among patients diagnosed with a cervical vertebrae fracture on CT supports WTA guidelines which recommend for a spine consultation for this patient cohort where MRI is often the next step in evaluating patient injury.

Refining imaging guidelines to advance patient care is a constantly evolving process. In 2009, the Eastern Association for the Surgery of Trauma (EAST) recommended for C-spine clearance to be largely a clinical practice for awake and alert patients who have full neck range of motion and no evidence of neurologic deficit, distracting injury, or neck pain/tenderness [18]. While EAST largely deferred the role of MRI in C-spine clearance to the judgement of individual institutions, the notion of MRI having utility in trauma patient C-spine clearance was acknowledged by studies which detailed patients with benign C-spine CT findings but abnormal C-spine MRI findings [17,19–21]. In 2015, the EAST guidelines were updated and became similar to the WTA guidelines, recommending the removal of C-collars after negative findings on a high-quality C-spine CT scan alone in obtunded or unexaminable patients and de-emphasized the role of MRI after negative CT findings [16].

As our findings indicate that CT and MRI are complementary imaging modalities with CT being superior for bony injuries and MRI superior

**Table 4**
Paired Proportion Analysis of CT vs. MRI for Cervical Spine Vertebral Fractures and Soft Tissue Injury Among Unexaminable Patients (GCS ≤14).

| Injury | | | MRI+ | MRI- | p-value |
|---|---|---|---|---|---|
| Any C-Spine Injury | | CT+ | 73 | 45 | 0.005* |
| | | CT- | 77 | 112 | |
| **Vertebral Fracture** | C1 | **CT+** | 9 | 4 | 0.375 |
| | | **CT-** | 1 | 293 | |
| | C2 | **CT+** | 16 | 2 | 0.453 |
| | | **CT-** | 5 | 284 | |
| | C3 | **CT+** | 1 | 2 | 1.000 |
| | | **CT-** | 1 | 303 | |
| | C4 | **CT+** | 6 | 3 | 1.000 |
| | | **CT-** | 3 | 295 | |
| | C5 | **CT+** | 8 | 2 | 1.000 |
| | | **CT-** | 1 | 296 | |
| | C6 | **CT+** | 8 | 4 | 1.000 |
| | | **CT-** | 4 | 291 | |
| | C7 | **CT+** | 16 | 3 | 1.000 |
| | | **CT-** | 3 | 285 | |
| **Any Vertebral Fracture** | | **CT+** | 55 | 8 | 0.791 |
| | | **CT-** | 61 | 238 | |
| **Soft Tissue Injury** | Edema | **CT+** | 0 | 0 | – |
| | | **CT-** | 21 | 286 | |
| | Ligamentous Injury | **CT+** | 2 | 1 | <0.001* |
| | | **CT-** | 56 | 248 | |
| | Contusion | **CT+** | 13 | 0 | 1.000 |
| | | **CT-** | 0 | 294 | |
| | Hematoma | **CT+** | 0 | 4 | 1.000 |
| | | **CT-** | 3 | 300 | |
| | Disc Injury | **CT+** | 2 | 3 | <0.001* |
| | | **CT-** | 28 | 274 | |
| **Any Soft Tissue Injury** | | **CT+** | 51 | 38 | <0.001* |
| | | **CT-** | 75 | 143 | |

*Indicates statistical significance ($p < 0.05$).
Abbreviations: MRI = Magnetic Resonance Imaging, CT = Computerized Tomography.

**Table 5**
Paired Proportion Analysis of CT vs. MRI for Cervical Spine Vertebral Fractures and Soft Tissue Injury Among Examinable Patients (GCS = 15). Abbreviations: MRI = Magnetic Resonance Imaging, CT = Computerized Tomography.

| Injury | | | MRI+ | MRI- | p-value |
|---|---|---|---|---|---|
| Any C-Spine Injury | | CT+ | 136 | 46 | <0.001* |
| | | CT- | 130 | 196 | |
| **Vertebral Fracture** | C1 | **CT+** | 12 | 7 | 0.016* |
| | | **CT-** | 0 | 479 | |
| | C2 | **CT+** | 34 | 10 | 0.302 |
| | | **CT-** | 5 | 449 | |
| | C3 | **CT+** | 4 | 2 | 1.000 |
| | | **CT-** | 1 | 491 | |
| | C4 | **CT+** | 6 | 2 | 1.000 |
| | | **CT-** | 2 | 488 | |
| | C5 | **CT+** | 9 | 8 | 0.581 |
| | | **CT-** | 5 | 476 | |
| | C6 | **CT+** | 18 | 6 | 0.791 |
| | | **CT-** | 8 | 466 | |
| | C7 | **CT+** | 19 | 14 | 0.541 |
| | | **CT-** | 10 | 455 | |
| **Any Vertebral Fracture** | | **CT+** | 103 | 16 | 0.511 |
| | | **CT-** | 21 | 358 | |
| **Soft Tissue Injury** | Edema | **CT+** | 0 | 1 | <0.001* |
| | | **CT-** | 35 | 462 | |
| | Ligamentous Injury | **CT+** | 5 | 1 | <0.001* |
| | | **CT-** | 65 | 427 | |
| | Contusion | **CT+** | 13 | 0 | 1.000 |
| | | **CT-** | 0 | 485 | |
| | Hematoma | **CT+** | 1 | 3 | 0.035* |
| | | **CT-** | 12 | 482 | |
| | Disc Injury | **CT+** | 5 | 6 | <0.001* |
| | | **CT-** | 80 | 407 | |
| **Any Soft Tissue Injury** | | **CT+** | 76 | 2 | <0.001* |
| | | **CT-** | 53 | 367 | |

*Indicates statistical significance ($p < 0.05$).

**Table 6**
Unadjusted and Adjusted Odds of Mortality by Age, ISS, TBI Status, Examinable Status, C-collar Placement, C-spine injury Sustained, and ED-LOS.

| | Mortality Rate | Unadjusted OR (95% CI) | Adjusted OR (95% CI) |
|---|---|---|---|
| Age Cohort | | | |
| Geriatric | 2.9% | 1.561 (0.542, 4.494) | 0.740 (0.149, 3.664)‡<br>0.759 (0.148, 3.878)† |
| Adult | 1.9% | 1 [Reference] | 1 [Reference] |
| **Injury Severity Score** | | | |
| Severe | 6.9% | 9.667 (2.860, 32.677)* | 12.994 (1.674, 100.850)‡,*<br>13.749 (1.769, 106.879)†,* |
| Intermediate | 3.1% | 4.130 (1.096, 15.564)* | 3.211 (0.328, 31.425)‡<br>3.232 (0.329, 31.731)‡ |
| Low | 0.8% | 1 [Reference] | 1 [Reference] |
| **Examinable Status** | | | |
| Unexaminable | 4.6% | 7.884 (2.247, 27.664)* | 6.437 (1.717, 24.130)‡,*<br>8.200 (2.068, 32.509)†,* |
| Examinable | 0.6% | 1 [Reference] | 1 [Reference] |
| **Traumatic Brain Injury** | | | |
| Present | 4.4% | 3.421 (1.302, 8.989)* | 1.820 (0.641, 5.165)‡<br>1.881 (0.658, 5.381)† |
| Absent | 1.3% | 1 [Reference] | 1 [Reference] |
| **Present** | | | |
| GCS Severe | 8.6% | 9.554 (1.151, 79.330)* | 10.994 (0.955, 126.625)‡<br>14.759 (0.970, 224.624)† |
| GCS Moderate | 4.8% | 5.050 (0.303, 84.133) | 5.649 (0.293, 108.768)‡<br>7.459 (0.316, 175.912)† |
| GCS Mild | 1.0% | 1 [Reference] | 1 [Reference] |
| **Absent** | | | |
| GCS Severe | 7.1% | 10.077 (2.178, 46.625)* | 6.448 (1.114, 37.324)‡,*<br>5.434 (0.858, 34.417)† |
| GCS Moderate | 3.2% | 4.367 (0.473, 40.285) | 9.692 (0.738, 127.292)‡<br>10.989 (0.788, 153.207)† |
| GCS Mild | 0.8% | 1 [Reference] | 1 [Reference] |
| **C-Spine Injuries Sustained** | | | |
| Any C-Spine Injury | 2.6% | 1.934 (0.625, 5.987) | 1.356 (0.423, 4.345)‡<br>1.359 (0.421, 4.381)† |
| Contusion | 7.7% | 4.244 (0.919, 19.608) | 3.222 (0.606, 17.121)‡<br>3.187 (0.598, 16.993)† |
| Edema | 7.0% | 4.267 (1.345, 13.541)* | 2.762 (0.823, 9.271)‡<br>2.648 (0.786, 8.925)† |
| Hematoma | 4.3% | 2.176 (0.276, 17.147) | 1.655 (0.195, 14.020)‡<br>1.473 (0.172, 12.574)† |
| C1–C7 Fracture | 3.8% | 2.596 (0.988, 6.819) | 2.128 (0.786, 5.759)‡<br>2.001 (0.734, 5.457)† |
| Ligamentous Injury | 3.8% | 2.210 (0.765, 6.383) | 1.898 (0.608, 5.927)‡ |

(continued on next page)

**Table 6** (*continued*)

| | Mortality Rate | Unadjusted OR (95% CI) | Adjusted OR (95% CI) |
|---|---|---|---|
| | | | 1.968 (0.625, 6.200)† |
| Disc Injury | 0.8% | 0.338 (0.044, 2.571) | 0.265 (0.034, 2.086)‡ |
| | | | 0.231 (0.036, 2.233)† |
| No C-Spine Injury | 1.3% | 1 [Reference] | 1 [Reference] |
| **C-Collar Placement** | | | |
| In-Hospital | 2.6% | 2.080 (0.459, 9.424) | 1.948 (0.685, 5.538)‡ |
| | | | 2.015 (0.700, 5.800)† |
| Pre-Hospital | 2.4% | 1.931 (0.526, 7.086) | 1.114 (0.380, 3.263)‡ |
| | | | 1.288 (0.429, 3.862)† |
| No C-Collar placement | 1.3% | 1 [Reference] | 1 [Reference] |
| **ED-LOS** | | | |
| <1 Hour | 0.0% | ~ | ~ |
| 1–1.99 Hours | 3.4% | 1.565 (0.417, 5.877) | 0.944 (0.223, 3.992)‡ |
| 2–3.99 Hours | 1.9% | 0.865 (0.191, 3.927) | 0.689 (0.140, 3.391)‡ |
| 4–5.99 Hours | 1.1% | 0.472 (0.048, 4.608) | 0.496 (0.049, 5.053)‡ |
| ≥6 Hours | 2.2% | 1 [Reference] | 1 [Reference] |

‡Adjusted for age, race, gender, ISS, and Charleston Comorbidity Index where one these variables are not the primary outcome of interest.
†Adjusted for age, race, gender, ISS, Charleston Comorbidity Index, and ED-LOS where one these variables are not the primary outcome of interest.
*Indicates statistical significance ($p < 0.05$).
Abbreviations: C-Collar = Cervical Spine Collar; C-Spine = Cervical Spine; CI = Confidence Interval; GCS = Glasgow Coma Scale; TBI = Traumatic Brain Injury; OR = Odds Ratio; ISS= Injury Severity Score; ED-LOS = emergency department length of stay.

in soft tissue injuries, indications for their use need to be clearly defined. This notion is highlighted by a previous study of the National Trauma Data Bank which showed variation in MRI utilization for blunt traumatic injury patients ranging from 0 to 68%, with cited reasons for this wide variability including a lack of physician consensus and/or failure of physicians to adopt recent evidence-based guidelines [22]. Furthermore, our findings that MRI was superior in detecting a subset of C-spine soft tissue injuries supports previous algorithms established by the WTA which recommend MRI for C-spine clearance only in patients who have an abnormal neurologic exam including ongoing central neck pain, or have an injury identified on CT [6]. In combination with our findings, this recommendation may imply that there is limited utility of MRI in the acute setting for patients without findings of C1–C7 vertebral fracture identified on CT and may allow the patient to receive definitive care earlier than waiting for MRI clearance [6,23]. However, as being unexaminable was associated with significantly higher odds of mortality and had differing concordance rates between CT and MRI for the detection of several soft tissue injuries, revision of EAST and WTA guidelines to include greater use of MRI in unexaminable patients may help to avoid missed injuries in these patients. Detecting all injuries sustained by a patient not only has relevance for their management and treatment plans but also has the potential to increase a patient's confidence and overall satisfaction with the care delivered by healthcare providers [24,25].

Duration of C-Collar placement has previously been cited in the literature as a variable that could potentially lead to increased patient mortality due to increases in intracerebral pressure and reduction of cerebral venous return [16,26–31]. Previous studies have found that C-collar placement has less of a role in improving mortality in comparison to other influential factors such as the quality of field resuscitation by EMS, pre-hospital transport time, and the quality of care delivered [32,33]. However, it is worth noting that although patients who had C-collar placement were found to have higher raw mortality rates than patients with no C-collar placement, it is possible that patients with a C-collar placed inherently possessed a higher mortality rate due to the nature of their injuries rather than deleterious effects of C-collar placement itself. For every 50–100 patients in whom a C-collar is placed, one patient is likely to have suffered from a significant spinal injury [34].

In comparing CT and MRI in the detection of C-spine injuries, it was found that CT was able to rule out nearly all cervical vertebrae fractures with a negative predictive value of 98.3–99.9%, outperforming MRI in the detection of C1 vertebral fracture. However, McNemar's paired proportion analysis revealed MRI was superior in ruling out most soft tissue injuries including soft tissue edema, ligamentous injury, and disc injury. As adjusted odds of mortality were not significantly increased for the soft-tissue injuries evaluated, the question of what role MRI plays in the acute setting for detecting soft tissue injuries in the process of C-spine clearance and initial management of the traumatically injured remains. There is a small degree of utility in performing additional imaging, even if the discovery of associated injuries does not change trauma patient outcomes or management in the acute setting. Patients may leave the hospital unhappy and questioning their quality of care if they are discharged with ongoing complaints which are then later diagnosed by other physicians, even if the second injury needs only expectant treatment. For example, an unideal situation is that of patients wondering why a primary care provider was able to diagnose a ligamentous injury on an outpatient basis, however the TC which treated their initial injuries was unable to make this diagnosis. Additionally, the anxiety associated with continued pain without a clear diagnosis to explain their symptoms could produce significant anxiety in patients and warrants caution in restricting more advanced diagnostic imaging in the acute setting.

Previous studies found that although MRI is helpful in identifying certain injuries not identified by CT scans, only a minority of these additional injuries discovered required surgical intervention in the acute setting, concluding that routine use of MRI for C-spine injuries is not warranted [9,16,35]. Thus, it may be more appropriate to defer diagnosis on these findings until after the patient receives definitive care and stabilization. In addition, patients who are unexaminable on arrival and have a negative C-spine CT may be examinable a short time later. This coupled with the high NPV of CT in detecting most injuries but not all, might indicate that if the patient remains unexaminable then the safest pathway may be to get an MRI during the hospitalization.

To the best of our knowledge, our study is unique in that it directly stratifies traumatic injuries by cervical injury level, as well as differing types of soft tissue injuries by utilizing radiologic data from our TC in relation to patient outcomes. This has allowed us to demonstrate the predictive values of both CT and MRI with respect to different and specific traumatic injuries, allowing a greater clinical context for our findings. However, there are several limitations to our study. First, our study is subject to inherent limitations associated with all retrospective cohort studies such as an inability to evaluate for causation. Secondly, our findings are subject to limitations associated with databases, including a possible minimal degree of human error in accurate entry of patient data into the trauma registry. Thirdly, due to a lack of data availability, we were unable to assess the impact of C-collar placement and other variables analyzed on the long-term functional status or disability of patients who survived their injuries. Future studies could expand on our analysis by performing similar investigations utilizing multi-institutional or national databases while incorporating information regarding long-term functional status, as well as EMS data regarding initial resuscitation received in the field, to allow greater analysis of the factors which play a role in C-spine injury patient morbidity and mortality.

We offer several recommendations moving forward. First, we recommend adoption of guidelines similar to official organizations such as WTA and EAST to eliminate any unnecessary MRI imaging which might delay definitive treatment for patients. We concur with the WTA and EAST guidelines that patients with ongoing symptoms, ongoing central neck tenderness, or cervical fracture indicated on CT should have a subsequent MRI. As MRI detected additional injuries undiagnosed by CT in unexaminable patients, we recommend for update of the WTA guidelines to recommend for MRI in patients who remain unexaminable after initial patient stabilization to assess for additional soft-tissue injuries [11,15,16]. We also recommend for future studies to build upon our analysis by examining additional patient outcomes, such as permanent disability and neurologic dysfunction, C-collar placement, and EMS transport time/initial field resuscitation received to identify areas for intervention to reduce patient morbidity.

## 5. Conclusion

The odds of mortality were significantly higher for unexaminable patients and those with a severe ISS. CT was found to be superior in the detection of C1–C7 vertebral fracture compared to MRI imaging. MRI was superior to CT in detecting soft tissue injuries and cord injuries such as cord edema in comparison to CT. This study supports imaging guidelines set forth by the WTA and EAST except for patients who remain unexaminable, in which we recommend an MRI. Additional research is needed to support alteration of current C-spine clearance guidelines to include more specific protocols for the use of C-collar placement in relation to long-term functional outcomes/disabilities and the role of MRI in the initial management of known or suspected C-spine injuries.

## Ethical Approval

This study was conducted in compliance with ethical standards, reviewed by our institutional review board and deemed exempt.

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None.

## Author contribution

Study design and conception: AE, MM, Data collection, analysis and interpretation: AE, MS, MM, Manuscript preparation and drafting: MS, MB, MM, AE, Critical revision of manuscript: MS, MB, MM, AE, All authors read and approved the final manuscript.

## Research Registration Unique Identifying Number (UIN)

This work was submitted to the Research registry (UIN #: researchregistry6858) which can be found via the following link: (https://www.researchregistry.com/browse-the-registry#home/registrationdetails/60ad7378266be10020221734/).

## Guarantor

Mark McKenney.

## Trial registry number

Not applicable.

## Provenance and peer review

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## Declaration of competing interest

Authors declare no competing interests.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amsu.2021.102566.

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