Original Article

Diagnostic accuracy and Prognostic Significance of point-of-care ultrasound (POCUS) for traumatic cervical spine in emergency care setting: A comparison of clinical outcomes between POCUS and computed tomography on a cohort of 284 cases and review of literature

ABSTRACT

Background: The cervical spine is injured in approximately 3% of major trauma patients, and 10% of patients with serious head injury. Therefore, clearance of the cervical spine in multitrauma patients is a critically important task. This is particularly important, considering that there is a positive correlation between a Glasgow Coma Scale of <14 and cervical spine injury. Radiography is not sensitive enough to rule out cervical spine injury, especially as radiography done in the trauma setting is usually technically unsatisfactory.

Objective: The current study aims to assess the diagnostic accuracy and prognostic significance of using bedside point-of-care ultrasound (POCUS) in traumatic cervical spine injuries compared to computed tomography (CT) as the reference standard.

Materials and Methods: This comparative study enrolled 284 patients with severe multiple trauma at a tertiary care center between July 2017 and March 2020. The inclusion criteria included an indication of cervical spine CT scan, satisfaction of patients with participation in the study, and the lack of history of injury and severe traumatic events. The exclusion criteria were the history of a previous cervical spinal trauma, spondylosis, scoliosis, spinal tuberculosis, degenerative vertebral changes, and patients who refused to give consent to participate in research or CT scanning. The data were analyzed by SPSS software, and sensitivity, specificity, and positive predictive value (PPV)/negative predictive value (NPV) were determined based on CT findings.

Results: The best window for the cervical spine was through the anterior triangle using the linear array probe (6–13 MHz). POCUS had a sensitivity of 78.5%, specificity of 98.4%, PPV of 93.2%, NPV of 92.8%, and accuracy of 93.2% in detecting all types of spinal injuries in comparison with CT scan as the standard modality. POCUS had a sensitivity of 100%, specificity of 92.3%, PPV of 62.3%, NPV of 100%, and accuracy of 91.7% in cases with the movement of injured particles. POCUS had a sensitivity of 32.2%, specificity of 100%, PPV of 100%, NPV of 91.4%, and accuracy of 90.8% in detecting the fracture of transverse process. POCUS had a sensitivity of 36.1%, specificity of 100%, PPV

INTRODUCTION

The cervical spine is injured in approximately 3% of major trauma patients, and 10% of patients with serious head injury. Therefore, clearance of the cervical spine in multitrauma patients is a critically important task.[1] Ideally, the spine will be cleared rapidly and accurately at the time of the patient's initial presentation to the emergency room. Multitrauma

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of 100%, NPV of 98.1%, and accuracy of 98.4% in 14-year age multitrauma patients. In comparison, the current study achieved a sensitivity of 79.4%, specificity of 95.7%, PPV of 92.1%, NPV of 86.3%, and accuracy of 88.6% in >14-year age multitrauma patients.

Conclusion: POCUS for cervical spine is feasible using portable ultrasound machine and by neurosurgeons/radiologists/emergency physicians with basic training. It holds great potential in resource-starved settings and in unstable patients for ruling out unstable cervical spine injuries and injuries associated with the movement of fractured or dislocated particles. POCUS examination of the cervical spine was possible in the emergency setting and even in unstable patients and could be done without moving the neck. Future studies, ideally conducted as randomized control trials, are required to establish training and education standards, and to assess the feasibility and safety of POCUS as an alternative to radiography.

Keywords: Cervical spine clearance, point-of-care ultrasound, traumatic cervical spine

patients are frequently unstable, and often have multiple organ system injuries for which treatment must be prioritized. In some patients, definitive evaluation of the cervical spine must defer to the management of severe hemodynamic instability or severe intracranial injury. The initial emergency room trauma evaluation attempts to elicit cervical spine pain or tenderness, or neurologic deficit. These physical findings are reported to have a sensitivity of 93% for cervical spine injury, but a specificity of only 16%.[2] Neck discomfort without other positive signs and symptoms has a reported sensitivity of 86%.[3] Unfortunately, multitrauma patients often have head injuries that limit the validity of the physical evaluation. This is particularly important, considering that there is a positive correlation between a Glasgow Coma Scale (GCS) of <14 and cervical spine injury.[4] It is possible to delay clearance of the cervical spine in multitrauma patients past the period of initial injury, and to maintain the patients in hard cervical collars. However, hard collars may not entirely prevent motion. In addition, they are associated with soft-tissue abrasions in the neck, and they complicate nursing care, especially if a patient is intubated.

In most Level 1 trauma centers, a lateral plain radiograph of the cervical spine is obtained at the time of initial presentation if a patient is obtunded or has neck pain. In some centers, it is obtained in all multitrauma patients. The lateral cervical spine radiograph is estimated to detect between 60% and 80% of cervical spine fractures.[5] Radiography is not sensitive enough to rule out cervical spine injury, especially as radiography done in the trauma setting is usually technically unsatisfactory. Patients, therefore, continue to have their cervical spine immobilized in cervical collar till the cervical spine is cleared by computed tomography (CT) spine.

Unfortunately, the delay in getting imaging done makes it difficult to conduct various procedures such as examination of back, intubation, and patient shifting, especially in hemodynamically unstable patients. Nearly all of the structures within the spine have been shown to be clearly visible via ultrasonography imaging including musculature, bones and intervertebral discs, nerve roots, the spinal cord, dura mater, facet joints, and foramen. If point-of-care ultrasound (POCUS) can reliably pick up potentially unstable cervical spine fractures, it will cause a paradigm shift in the management of these patients with the potential to revolutionize emergency health care for severe head-injured patients in most parts of the world.[6] This study assesses the diagnostic accuracy of using POCUS to detect unstable cervical spine injuries in unconscious patients with severe head injury.

Objective

The current study aims to assess the diagnostic accuracy and prognostic significance of using bedside POCUS in traumatic cervical spine injuries compared to CT as the reference standard.

MATERIALS AND METHODS

Study setting and protocol

This comparative study enrolled 284 patients with severe multiple trauma at a tertiary care center between July 2017 and March 2020. The inclusion criteria included an indication of cervical spine CT scan, satisfaction of patients with participation in the study, and the lack of history of injury and severe traumatic events. The exclusion criteria were the history of a previous cervical spinal trauma, spondylosis, scoliosis, spinal tuberculosis, degenerative vertebral changes, and patients who refused to give consent to participate in research or CT scanning.

The indications of cervical CT scan in patients included the loss of consciousness (LOC) or focal neurological deficits (FNDs), severe multiple trauma, clinical signs and symptoms of spinal injury, midline spinal pain or tenderness, stepping, and abnormal findings on conventional radiography. The disease severity was determined according to either the GCS (score: 3–15). Multitrauma patients with GCS scores of <12 were

considered to have severe trauma. Immediately after presentation to the Emergency Department, the therapeutic team followed the advanced trauma life support (ATLS) approach and provided routine diagnostic and therapeutic measures for all patients. The US examination was performed following secondary survey and initial stabilization and before CT scanning. All Ultrasound examinations were carried out through a linear probe (7.5 MHz) by a single operator using an available portable machine (General Electric, LogiQ 500 MD, GE Medical Systems, Milwaukee, WI, USA). The anterior triangle of the neck was used as the routine window for cervical spine US examination. The region was located at the front of the neck and was restricted superiorly to the inferior margin of the mandible, laterally to the anterior rim of the sternocleidomastoid muscle, and medially to the midline of the neck. Throughout the US process, the patient's head and neck were fixed and held manually by a trained person, standing above the patient's head. Immediately after the end of US examination, the neck collar was fixed by the help of assistance.

Point-of-care ultrasound technique

Posterior window

In the current study, sonographic evaluation of the affected region was performed using a high-frequency (6–13 MHz) linear array probe placed on the back of the neck of volunteers. The image quality was excellent, with the additional advantage of cervical canal being nicely visible. However, this method is impractical in patients with suspected cervical spine injury as the posterior window is not available to the examiner, except during log rolling.

Anterior window

Keeping the same linear probe in the anterior triangle of the neck provides satisfactory image quality and allows one to assess the cervical spine from C2 to D1 and see for canal compromise, ligamental injury, and major fractures. This window was subsequently used for assessing the cervical spines in admitted patients with known cervical spine injuries. A "potentially unstable cervical spine injury" was defined as any degree of dislocation with loss of continuity of the anterior longitudinal ligament.

All cervical spine CT scans were performed by a 16-slice CT scanner GE (General Electric Medical Systems, Milwaukee, WI, USA). The CT scan findings were reported by the same radiologist who performed POCUS. During the hospitalization, the studied variables including age, sex, initial consciousness level (GCS score), mechanism and severity of trauma, trauma to admission interval, need for intubation, mortality, hospitalization (surgery or ICU), need for surgery, and POCUS and CT scan findings were collected and recorded. The researcher was blind to the CT scan findings until the end of the study. Final data were matched between the US findings and CT findings.

Statistical analysis

Collected data were tabulated using Microsoft Excel 2010 Microsoft Corp., Redmond, WA, USA, and statistical analyses were conducted using SPSS Statistical Package (version 20.0), IBM SPSS Statistics for Windows, V.20.0, IBM Corp., Armonk, NY, USA. First, the normal distribution of values was assessed using the Kolmogorov–Smirnov test, and then, the descriptive statistics (mean and standard deviation) were used for comparing the two groups in terms of quantitative and qualitative variables. Sensitivity, specificity, positive predictive value/negative predictive value (PPV/NPV), and positive/negative likelihood ratio of POCUS were determined based on CT scan findings in detecting cervical spine injuries. Moreover, the results were compared between children (≤14 years) and adult (>14 years) age groups. In all cases, $P < 0.05$ was considered statistically significant.

Ethical considerations

All examinations performed in studies involving human participants were in accordance with the ethical standards of the institutional ethics committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all patients prior to their enrollment in this study.

RESULTS

Overall, 284 polytrauma patients were studied including 74 (26.0%) female patients and 210 (74.0%) male patients. The patients were in the age range of 1–95 years (mean: 23.2 ± 22.4 years); 112 (39.6%) patients were ≤14 years of age and 172 (60.4%) were >14 years of age. The ranges of other variables on admission were as follows: O_2 saturation: 82%–97% (mean: 94.8 ± 3.8), systolic blood pressure: 60–180 mmHg (mean: 110.5 ± 18.5), diastolic blood pressure: 38–112 mmHg (mean: 68.2 ± 10.8), respiratory rate: 12–38/min (mean: 19.2 ± 4.6), and heart rate: 68–144/min (mean: 102.1 ± 11.2). The trauma to admission interval was <1 h in 176 (62%) patients, 1–2 h in 83 (29.4%) patients, 2–6 h in 18 (6.2%) patients, and >6 h in 7 (2.4%) patients. The mechanism of trauma was passenger accident in 182 (64.2%) patients, falling from height in 64 (22.4%) patients, pedestrian accident in 23 (7%) patients, assault in 8 (2.8%) patients, hanging in 7 (2.4%) patients, and falling down in 3 (1.2%) patients.

The patients' GCS scores on admission were 6–11, including GCS = 6 in 4 patients (1.4%), GCS = 7 in 10 patients (3.4%), GCS = 8

in 24 patients (8.3%), GCS = 9 in 40 patients (14.2%), GCS = 10 in 59 patients (20.8%), and GCS = 11 in 147 patients (51.9%). Totally, 69 patients (24.2%) needed intubation on admission and 4 patients (1.4%) were expired in the emergency room because of the severity of injuries, concomitant brain injury, and multi-organ involvement. The most common findings on admission were LOC in 236 patients (83.2%), FND in 28 patients (9.8%), neck tenderness in 11 patients (3.8%), severe headache in 5 patients (1.7%), and both severe headache and neck tenderness in 4 patients (1.5%). The findings of POCUS were as follows: intactness in 225 patients (79.4%), fracture of vertebral body in 29 patients (10.3%), dislocation of vertebral body in 21 patients (7.4%), fracture of transverse process in 6 patients (2.1%), fracture of vertebral body and hematoma in 5 patients (1.7%), and fracture and dislocation of vertebral body in 2 patients (0.8%). The findings of cervical spine CT scan were as follows: intactness in 211 patients (74.4%), fracture of vertebral body in 30 patients (10.6%), dislocation of vertebral body in 20 patients (7.2%), fracture of transverse process in 19 patients (6.8%), fracture of vertebral body and hematoma in 3 patients (1.2%), and fracture and dislocation of vertebral body in 2 patients (0.8%).

After stabilization and disposition in the emergency room, the patients were admitted to the wards. The mean duration of hospitalization was 3.8 ± 3.2 days (range: 1–20 days). Of all patients, 69 (24.2%) needed intubation after hospitalization because of alteration in GCS. Furthermore, 192 patients (67.7%) needed surgery, including spinal surgery in 94 cases (33.2%), craniotomy in 29 cases (10.2%), and nonneurosurgical operations in 69 cases (24.3%). Finally, 49 cases (17.3%) were expired after hospitalization. The collected data were analyzed to evaluate the diagnostic value of POCUS in detecting cervical spine injuries in comparison with CT scan as the reference standard modality, and the results are shown in Table 1. The diagnostic value of POCUS was higher in injured cases with the movement of fractured or dislocated particles. Table 2 shows the diagnostic value of POCUS in detecting spinal injuries with the movement of fractured or dislocated particles in comparison with CT scan as the gold standard modality. The diagnostic value of POCUS in detecting the fractures of transverse process is shown in Table 3. Furthermore, as one of the goals of this study, the value of POCUS in detecting cervical spine injuries was compared in multitrauma patients aged ≤14 years and >14 years, and the results are shown in Table 4.

Table 1: Diagnostic value of point-of-care ultrasound in detecting spinal injuries

Statistical parameter	Value (%)	95% CI
Sensitivity	78.5	63.4-92.2
Specificity	98.4	97.2-99.7
PPV	93.2	81.3-98.1
NPV	92.8	87.1-95.4
Accuracy	93.2	88.7-96.3

CI - Confidence interval, NPV - Negative predictive value, PPV - Positive predictive value

Table 2: Diagnostic value of point-of-care ultrasound in detecting spinal injuries with the movement of fractured or dislocated particles

Statistical parameter	Value (%)	95% CI
Sensitivity	100.0	88.4-100.00
Specificity	92.3	88.1-94.3
PPV	62.3	58.7-62.4
NPV	100.0	-
Accuracy	91.7	89.2-93.1

CI - Confidence interval, NPV - Negative predictive value, PPV - Positive predictive value

Table 3: Diagnostic value of point-of-care ultrasound in detecting fracture of transverse process

Statistical parameter	Value (%)	95% CI
Sensitivity	32.2	8.2-54.3
Specificity	100.0	96.3-100.00
PPV	100.0	95.7-100.00
NPV	91.4	89.4-93.5
Accuracy	90.8	88.1-92.7

CI - Confidence interval, NPV - Negative predictive value, PPV - Positive predictive value

Table 4: Diagnostic value of point-of-care ultrasound in detecting cervical spine injuries in 14-year age and >14-year age multitrauma patients

Statistical parameter	≤14-year age		>14-year age	
	Value (%)	95% CI	Value (%)	95% CI
Sensitivity	36.1	4.2-94.5	79.4	64.2-89.1
Specificity	100.0	96.1-100.00	95.7	87.1-99.0
PPV	100.0	-	92.1	78.4-96.7
NPV	98.1	94.4-98.9	86.3	78.3-94.8
Accuracy	98.4	91.1-99.2	88.6	79.7-94.7

CI - Confidence interval, NPV - Negative predictive value, PPV - Positive predictive value

DISCUSSION

There is a scarcity of published articles regarding the use of bedside POCUS for evaluating spine injuries in patients with severe multiple trauma. The current study evaluated the diagnostic value of US in detecting cervical spine injuries compared to CT as the reference method. Furthermore, the role and usefulness of bedside POCUS were assessed in evaluating the cervical spine of acutely injured patients. To date, there is no suitable technique for early cervical spine clearance in unstable polytrauma patients in the field or EDs during initial resuscitation.[7] Being available and commonly used by trauma and emergency specialists, bedside POCUS is utilized effectively in this domain. However, there are a few published studies on the value of bedside POCUS in cervical spine clearance in patients with severe multiple

trauma. Bedside POCUS has been used as an essential part of trauma patients' examination in EDs for two decades that has resulted in reduced mortality. This modality is used routinely at tertiary care centers by emergency medicine specialists and residents for all multiple trauma patients as a step of ATLS. While cervical spine fractures occur in only 0.7% of all blunt trauma patients and constitute 19.38% of all spine fractured patients, failing to diagnose this relatively small proportion could lead to catastrophic neurologic disability.[8] The US modality provides a useful adjunct for emergency physicians in evaluating multiple trauma patients and achieving notable information in a short span of time. The current study enrolled and assessed severe multiple trauma patients with altered consciousness. It has been reported that a notable proportion (18%–26%) of unconscious trauma patients have associated cervical spine injury.[9] There are two approaches for the sonographic evaluation of cervical spine, involving posterior and anterior windows. The preferred approach in severe multiple trauma patients is the anterior window, which offers satisfactory image quality and allows for the assessment of cervical spine, canal compromise, soft-tissue injury, and major fractures. All US examinations were performed by a linear array probe (7.5 MHz) available in the ED through the anterior window. The probe was located over the anterior triangle of the neck for optimum resolution. Agrawal *et al*.[10] preferred the anterior triangle as the window for cervical spine evaluation using a linear probe (6–13 MHz). Contrary to the current research, Meinig *et al*.[11] used prone or lateral decubitus position for the sonographic evaluation of posterior ligament injuries in a secure and straight head position with support cushions for cervical trauma patients.

In the current study, POCUS had a sensitivity of 78.5%, specificity of 98.4%, PPV of 93.2%, NPV of 92.8%, and accuracy of 93.2% in detecting all types of spinal injuries in comparison with CT scan as the standard modality. Agrawal *et al*.[10] concluded that bedside US through the anterior window allowed to assess the cervical spine from C2 to T1 for major fractures. The current study also observed that the diagnostic value of POCUS was higher in major fractures with the movement of fractured or dislocated particles. The current study achieved a sensitivity of 100%, specificity of 92.3%, PPV of 62.3%, NPV of 100%, and accuracy of 91.7% in cases with the movement of injured particles.

Although numerous articles have been published about the use of POCUS in the emergency setting, studies of its use in spine injuries are limited. However, it has been suggested that trained emergency medicine residents may be able to perform POCUS with high diagnostic value in trauma patients.[6] If the POCUS could reliably discover cervical spine severe injuries and fractures, it could cause a pronounced improvement in the management of these patients and marked progress in emergency care for severe polytrauma patients.

Berg *et al*.[12] used US for the evaluation of equine cervical vertebral and paravertebral structures and found consistency between US imaging and corresponding postmortem cross-sectional imaging. Agrawal *et al*.[10] could easily detect fracture lines, canal compromise, and ligament injury in all studied cases of severe trauma through bedside US. Among 10 patients, bilateral facet dislocation was seen in seven patients, burst fracture in one patient, and anterolisthesis in one patient. POCUS has been suggested as an alternative primary technique in the diagnosis of bone fractures, especially in pregnant women and children.

Moritz *et al*.[7] concluded that POCUS is comparable to radiography for the diagnosis of fractures and recommended the use of US examination as the primary imaging technique in pediatric trauma with nonspecific signs or unclear locations of pain, followed by radiography of the predefined region. Meinig *et al*.[11] suggested that magnetic resonance imaging (MRI) and US findings had a strong positive correlation in detecting posterolateral corner injuries, and US with a sensitivity of 0.82 and specificity of 1.00 produced results comparable with those of MRI and better than CT scan findings. In addition, von Scotti *et al*.[13] achieved a sensitivity of 83.3%, specificity of 93.8%, NPV of 83.3%, and NPV of 93.8%. Vordemvenne *et al*.[14] used POCUS for detecting posttraumatic paravertebral hematoma with a sensitivity of 0.99 and specificity of 0.75. The prevalence of hematoma in the current study was very low in both US and CT findings, and thus, the results are not comparable. In the current study, POCUS had a sensitivity of 32.2%, specificity of 100%, PPV of 100%, NPV of 91.4%, and accuracy of 90.8% in detecting the fracture of transverse process. This relatively low sensitivity may be due to the unsuitableness of the anterior window for visualization of transverse process. In this study, POCUS had a sensitivity of 36.1%, specificity of 100%, PPV of 100%, NPV of 98.1%, and accuracy of 98.4% in ≤14-year age multitrauma patients. In comparison, the current study achieved a sensitivity of 79.4%, specificity of 95.7%, PPV of 92.1%, NPV of 86.3%, and accuracy of 88.6% in >14-year age multitrauma patients. Therefore, we obtained higher sensitivity in adults and higher specificity in pediatric trauma patients. The limited visualization due to the relatively small size of the anterior window in pediatric patients, as experienced in this study, may be an effective factor in achieving lower sensitivity in children. Furthermore, this discrepancy may originate from diversity in the type and severity of trauma and physical differences between the two age groups. As reported by previous studies, spinal injury is rare in pediatric trauma patients, accounting for only 1.5% of all blunt trauma

cases.[15] This was true in the current study, and the incidence of cervical spine injury was 1.7% in patients ≤14 years of age.

Unnecessary CT scanning increases radiation exposure and the risk of cancer in pediatric trauma patients. Adhering to a safe and accurate algorithm in pediatric trauma reduces radiation exposure and provides early and effective clearance of the cervical spine while avoiding missed catastrophic injuries. It has been suggested that POCUS can serve better than radiography for the detection of fractures in children.

Limitations of the study

The research was conducted at a single center. It is recommended conducting a multicenter survey with more variables and larger sample sizes. Furthermore, the posterior cervical window could yield an excellent image quality with another advantage of visualization of spinal canal; however, because this technique needs logrolling and is unpractical in patients with suspected cervical spine injury, it was not used in this study. POCUS being operator dependent, the results can vary depending on the person doing the scan. However, this holds true for focused abdominal POCUS in trauma which has now become the de facto standard for abdominal trauma. Furthermore, as the consequences for missing a cervical injury can be disastrous, POCUS is recommended to be used only as an adjunct to cervical radiographs/CT cervical spine.

CONCLUSION

POCUS for cervical spine is feasible using portable ultrasound machine and by neurosurgeons/radiologists/emergency physicians with basic training. It holds great potential in resource-starved settings and in unstable patients for ruling out unstable cervical spine injuries and injuries associated with the movement of fractured or dislocated particles. POCUS examination of the cervical spine was possible in the emergency setting and even in unstable patients and could be done without moving the neck. Future studies, ideally conducted as randomized control trials, are required to establish training and education standards, and to assess the feasibility and safety of POCUS as an alternative to radiography.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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