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Clinical Studies

The utility of vertebral Hounsfield units as a prognostic indicator of adverse events following treatment of spinal epidural abscess

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ABSTRACT

Background: Spinal epidural abscesses (SEAs) are a devastating condition with high levels of associated morbidity and mortality. Hounsfield units (HUs), a marker of radiodensity on CT scans, have previously been correlated with adverse events following spinal interventions. We evaluated whether HUs might also be associated with all-cause complications and/or mortality in this high-risk population.

Methods: This retrospective cohort study was carried out within an academic health system in the United States. Adults diagnosed with a SEA between 2006 and 2021 and who also had a CT scan characterizing their SEA within 6 months of diagnosis were considered. HUs were abstracted from the 4 vertebral bodies nearest to, but not including, the infected levels. Our primary outcome was the presence of composite 90-day complications and HUs represented the primary predictor. A multivariable logistic regression analysis was conducted adjusting for demographic and disease-specific confounders. In sensitivity testing, separate logistic regression analyses were conducted (1) in patients aged 65 and older and (2) with mortality as the primary outcome.

Results: Our cohort consisted of 399 patients. The overall incidence of 90-day complications was 61.2% (n=244), with a 7.8% (n=31) 90-day mortality rate. Those experiencing complications were more likely to have undergone surgery to treat their SEA (58.6% vs. 46.5%; p=.018) but otherwise the cohorts were similar. HUs were not associated with composite 90-day complications (Odds ratio [OR] 1.00 [95% CI 1.00—1.00]; p=.842). Similar findings were noted in sensitivity testing.

Conclusions: While HUs have previously been correlated with adverse events in certain clinical contexts, we found no evidence to suggest that HUs are associated with all-cause complications or mortality in patients with SEAs. Future research hoping to leverage 3-dimensional imaging as a prognostic measure in this patient population should focus on alternative targets.

Level of Evidence: Level III; Observational Cohort study.

Background

Hounsfield units (HU) are a marker of radiodensity on computed tomography (CT) scans. They represent a transformation of the linear attenuation coefficient of a particular portion of an image, with water (0 HUs) and air (−1,000 HUs) at standard pressure and temperature as references [1]. Recently, several authors have noted a correlation between HUs and mechanical complications following different spine surgical interventions [2–10]. This association seems to be due, at least in part, to the relationship between HUs, bone mineral density, and osteoporosis [1]. This connection has led some authors to postulate that HUs might represent opportunistic markers of frailty as well. However, to our knowledge there has never been an investigation conducted with the goal of elucidating this possible association within a patient popu-

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FDA device/drug status: Not applicable.

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lation seeking spine-related care. In this context, we sought to evaluate whether vertebral HUs are associated with poor outcomes in a substrate population at high risk for both baseline frailty and posttreatment complications: patients with spinal epidural abscess (SEA).

In prior research, several factors have been identified as influencing outcomes following treatment of SEA [11–22]. Many of these variables, such as age and medical comorbidities, are more closely related to the baseline health of the patient than the severity of their infection. Furthermore, 3 critical risk factors for the development of SEA, namely advanced age, immunocompromise and intravenous drug use are all clinical entities correlated with physiologic frailty [16,17,19,20,23]. As such, the SEA patient population was determined to be a well-balanced cohort on which to test the potential association between HUs and adverse events following treatment.

We specifically sought to analyze whether opportunistically gathered HUs were associated with complications among patients receiving initial treatment for SEA. Our primary aim was to investigate this potential association with 90-day composite complications as the outcome of interest. We additionally performed sensitivity analyses to determine whether an association exists when only considering patients aged 65 and older or when exclusively focused on mortality. We hypothesized that lower HU values would be associated with a greater likelihood of adverse events following treatment for SEA.

Methods

This retrospective cohort study was conducted within one large health system composed of 2 academic medical centers and 2 community-based hospitals located within a major metropolitan area in the United States. Our institutional review board approved of this work prior to commencement (approval number 2021P000050).

Potentially eligible patients were adults who were diagnosed with a SEA from 2006 to 2021 and who had a CT scan that involved their spine within 6 months of their diagnosis. Patients were identified through a query of our institution's Research Patient Data Registry . In brief, Research Patient Data Registry is an internally maintained registry that combines clinical and billing related information. It has been utilized for numerous works within the orthopedic and spine literature in the past including studies of SEA [11,14,22,24,25]. Patients were excluded if their CT scans were severely motion degraded, if they were diagnosed with abscesses that spanned the entirety of their spine (due to inability to abstract vertebral HUs outside of the scope of the infection), and if they had prior surgical instrumentation obstructing HU measurement.

Hounsfield units were abstracted from the 4 levels of the spine nearest to, but not including, the site of infection. For example, if a patient had an epidural abscess at T8–9, the T6, T7, T10, and T11 levels would have been abstracted utilizing axial CT scan slices centered on the vertebral bodies of interest, in accordance with past literature (Figure) [26]. These values were abstracted by 2 physician authors (ICA and MHL), who a-priori demonstrated appropriate concordance in grading HUs on a sample population (intra-class correlation 0.91; p-value .006). The mean HU value of these 4 adjacent vertebral levels was utilized in the analysis. Additional variables that were abstracted included the region of the spine from which HUs were obtained, the location of the SEA, age, biologic sex, smoking status, Charlson comorbidity index, associated bacterial pathogen, the antibiotic(s) selected to combat the infection following culture sensitivities, intravenous drug use status, presenting symptoms (axial pain or no symptoms, radicular symptoms, or paresis/paralysis), preinfection ambulatory status (independent, dependent, or nonambulatory), whether spine surgery was performed, and the type of spine surgery performed, as indicated.

Complications were abstracted by manual chart review of the 90 days following diagnosis. All-cause complications were defined as: change in initial nonoperative management (with initial management defined by a spine surgery consult note), un-anticipated readmission, deep vein thrombosis, pulmonary embolism, acute delirium, aseptic wound complication, infectious wound complication, urinary complication (e.g. acute kidney injury, symptomatic urinary tract infection), pulmonary complication (e.g. pneumonia, chronic obstructive pulmonary disease exacerbation), sepsis, shock, or death.

Summary statistics are presented as means with 95% confidence intervals (CI) or percentages with frequencies. Crude comparative statistics were calculated with 2-sample t tests or chi-squared tests as appropriate. To answer our primary study aim, a multivariable logistic regression model was developed with 90-day all-cause complications as the primary outcome, mean HU as the primary predictor, and the following covariates: region of the spine from which HUs were abstracted, age, biologic sex, smoking status, bacterial isolate, intravenous drug use status, presenting symptoms, ambulatory status, and Charlson comorbidity index. Sensitivity analyses were conducted (1) in patients aged 65 and older and (2) with 90-day incidence of mortality as a secondary outcome, in multivariable logistic regression testing using the same covariates as in the primary model. Data maintenance and analysis were performed using Python v3.9.13 (Python Software Foundation) and Stata v17.0 (StataCorp).

Results

Our query generated 449 potential subjects. Patients were excluded on the basis of motion degradation of their CT scan (n=2), prior hardware (n=38), or the epidural abscess extending throughout the entire epidural space (n=10). Following exclusion, 399 patients remained in the analysis. A majority of these experienced 1 or more complications within 90 days of their diagnosis (n=244; 61.2%).

Patients who experienced complications within 90 days of their diagnoses differed from those who did not primarily on the basis of whether surgical intervention had been pursued. Patients who experienced complications were more likely to have had surgery to treat their SEA (58.6% vs. 46.5%; p=.018). A majority of those patients who received surgery underwent isolated decompressions (without fusion) in both groups. Differences were not noted between cohorts on the basis of age, biologic sex, smoking status, Charlson comorbidity index, intravenous drug use status, location of the SEA, bacterial isolate of the SEA, presenting symptoms, or preinfection ambulatory status (Table 1). The mean Hounsfield units of those without complications was 213.1, whereas the mean HUs of those with complications was 212.3 (p=.9331).

Complications occurred due to a variety of etiologies (Table 2). The most common complications were readmission and sepsis, representing 38.5% of the cohort experiencing complications. Overall, 31 patients died within 90 days of their diagnosis (7.8% of the cohort).

We found no evidence to support a correlation between Hounsfield units and all-cause complications after adjusting for confounders [OR 1.00 (95% CI 1.00-1.00); p=.842; Table 3]. Similar findings were noted following sensitivity testing as well. No association was noted between HUs and the 90-day mortality (OR 1.00 [95% CI 1.00–1.01]; p=.856) after adjusting for the same covariates. When the study population was restricted to only those aged 65 and older (n=155), no association was identified between HUs and 90-day all-cause complications (OR 1.00 [95% CI 1.00–1.01]; p=.533).

Discussion

In this investigation we sought to determine whether vertebral HUs were associated with complications in patients treated for SEAs. This investigation was carried out due to a theory that vertebral HUs may represent opportunistic markers of frailty that could be leveraged in ongoing efforts to predict and optimize patient care for this medically complex population. Nonetheless, our results indicated no evidence that vertebral HUs were predictive of 90-day all-cause complications, complications in patients aged 65 and older, or 90-day mortality following the diagnosis of SEA.

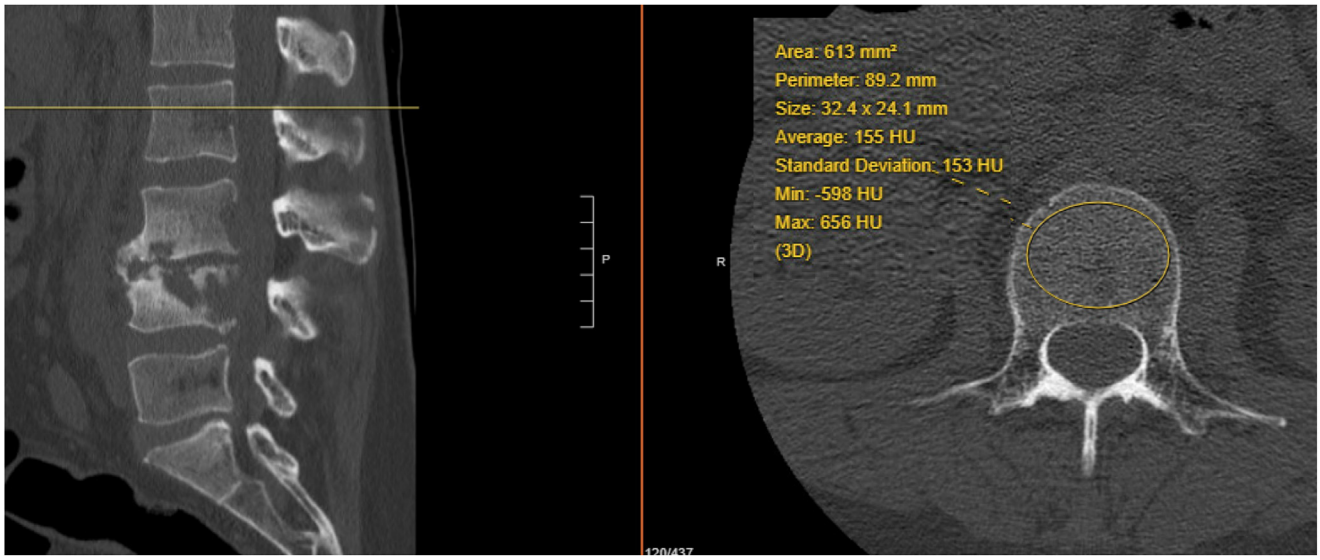

Figure. A representative patient with an epidural abscess and osteodiscitis at L3–4. For this patient, L2 Hounsfield units were measured as 155.

Table 1
Differences were between cohorts on the basis of age, biologic sex, smoking status, Charlson comorbidity index, intravenous drug use status, location of the SEA, bacterial isolate of the SEA, presenting symptoms, or preinfection ambulatory status.

Patient characteristics	Group without complications	Group with complications	p value
Total	155	244	
Age	57.2 (54.8–59.6)	59.7 (57.9–61.5)	.0932
Female	44.5 (69)	41.0 (100)	.486
Active smoker	40.7 (63)	40.2 (98)	.924
Charlson comorbidity index	4.5 (4.0–5.1)	5.1 (4.6-5.5)	.1491
Intravenous drug user	41.3 (64)	40.6 (99)	.887
Cranial extent of SEA			.9209
Cervical	20.7 (32)	20.5 (50)	
Thoracic	34.2 (53)	31.6 (77)	
Lumbar	44.5 (69)	47.5 (116)	
Sacral	0.7 (1)	0.41 (1)	
Bacterial isolate of SEA			.9434
MSSA	43.2 (67)	43.4 (106)	
MRSA	18.1 (28)	16.8 (41)	
E. coli	5.2 (8)	3.3 (8)	
Never known	2.6 (4)	2.9 (7)	
Streptococcus	9.0 (14)	10.3 (25)	
Polymicrobial	9.0 (14)	7.8 (19)	
Other	12.9 (20)	15.6 (38)	
Presenting symptoms			.8255
Axial pain/No symptoms	60.7 (94)	58.6 (143)	
Radicular symptoms	15.5 (24)	13.5 (33)	
Paralysis/Paresis	22.6 (35)	26.2 (64)	
Obtunded/Not obtainable	1.3 (2)	1.6 (4)	
Preinfection ambulatory status			.1982
Independent	78.7 (122)	71.7 (175)	
Dependent	19.4 (30)	23.8 (58)	
Nonambulatory	1.9 (3)	4.5 (11)	
Surgical intervention	46.5 (72)	58.6 (143)	.018
Surgery type			.0078
None	53.5 (83)	41.4 (101)	
Decompression	31.6 (49)	34.8 (85)	
Decompression and fusion	14.8 (23)	23.8 (58)	
Hounsfield units	213.1 (201.1–225.0)	212.3 (201.1–223.6)	.9331

Note: Continuous variables are presented as means (with 95% CI). Categorical and dichotomous variables are presented as percentages (with frequencies).
Abbreviations: SEA, spinal epidural abscess; MSSA, methicillin sensitive *Staphylococcus aureus*; MRSA, methicillin resistant *Staphylococcus aureus.*

Prior work has demonstrated that HUs are associated with mechanical complications for a variety of procedures involving spinal instrumentation [2–10]. For example, in their review of patients undergoing thoracolumbar fusions, Pinter et al. [8] reported that lower HUs at the upper instrumented vertebra were independently associated with both proximal junctional kyphosis and proximal junctional failure [8]. In that study, HUs performed better at predicting these failures than typical markers of frailty such as the modified frailty index or Charlson comorbidity index. Similarly, others have recently suggested that HUs are also predictive of screw loosening, [5,6] fracture following fusion,

Table 2
90-day complications.

All-Cause Complications	244
Change in initial nonoperative management	49 (20.1%)
Readmission	94 (38.5%)
Myocardial infarction	8 (3.3%)
Deep vein thrombosis	37 (15.2%)
Pulmonary embolus	11 (4.5%)
Delirium	61 (25.0%)
Aseptic wound issue	14 (5.7%)
Infectious wound issue	16 (6.6%)
Urinary complication	89 (36.5%)
Pulmonary complication	58 (23.8%)
Sepsis	94 (38.5%)
Shock	54 (22.1%)
Death	31 (12.7%)

Note: Patients may have experienced more than 1 complication.
Values are presented as frequencies (and percentages with reference to the 244 patients experiencing at least 1 complication).

Table 3
Logistic regression analysis with all-cause complications as outcome.

Patient characteristics	Odds ratio (95% CI)	p value
Hounsfield units	1.00 (1.00, 1.00)	.842
Region*		
Cervicothoracic	1.49 (0.38, 5.80)	.564
Thoracic	0.82 (0.35, 1.96)	.660
Thoracolumbar	1.10 (0.41, 2.95)	.849
Lumbar	0.93 (0.37, 2.32)	.869
Age	1.01 (0.99, 1.03)	.297
Male	1.13 (0.74, 1.72)	.575
Smoker	1.41 (0.23, 8.41)	.709
Bacterial isolate		
MRSA	1.65 (0.53, 5.17)	.387
MSSA	1.77 (0.61, 5.16)	.295
Never known	1.68 (0.33, 8.55)	.533
Other	1.90 (0.60, 6.04)	.274
Polymicrobial	1.40 (0.41, 4.83)	.595
Streptococcus	1.80 (0.53, 6.09)	.345
Intravenous drug use	0.80 (0.13, 4.77)	.805
Presenting symptoms		
Obtunded/Not obtainable	1.08 (0.18, 6.38)	.929
Paresis/Paralysis	1.20 (0.72, 2.01)	.485
Radicular	0.81 (0.44, 1.48)	.487
Ambulatory status		
Independent	0.87 (0.50, 1.52)	.635
Nonambulatory	2.30 (0.57, 9.34)	.244
Charlson comorbidity index	1.03 (0.96, 1.10)	.397

Abbreviations: MSSA, methicillin sensitive *Staphylococcus aureus*; MRSA, methicillin resistant *Staphylococcus aureus*.
* This is the region of the spine from which Hounsfield units were derived.

[7] mechanical complications following 3 column osteotomies, [3] and the loss of cervical lordosis following laminoplasty [4]. These works underscore an important association between vertebral HUs and bone quality-related complications, which should be expected given the relationship between HUs and osteoporosis [1].

The primary hypothesis driving this work was that vertebral HUs might offer a quantifiable snapshot into physiologic frailty in addition to bone health. Prior SEA research has demonstrated that certain patient-specific variables are indeed associated with poor outcomes. For example, diabetes [11–14], age greater than 65 [12], and active malignancy [13,14] have all been associated with failure of initial nonoperative management. Similarly, age [16,17,20], and medical comorbidities that are also associated with immunocompromise (i.e. end-stage renal disease, diabetes, and active malignancy) [16,17,19,20] have all been associated with mortality in patients with SEAs. Nonetheless, very few prognostic variables have been identified that utilize the 3-dimensional imaging that is common in this patient population [13,14]. As we continue to increasingly transition to value-based care, we believe that prognostic clues that can be obtained opportunistically will be increasingly valued by clinicians.

For these reasons, we believe the lack of a detectable association between HUs and complications in patients with SEAs does represent novel and important information. Our results demonstrate no evidence to suggest that an association between vertebral HUs and all-cause complications exists. In this context, it is also important to recognize that this lack of association is not due to imprecision across our point estimates. Given the size of our sample, the 95% CIs were tightly centered on a null estimate that remained essentially immutable in sensitivity testing. We believe that this represents an actionable, translatable finding and future research ventures should focus on alternative targets within 3-dimensional imaging that may represent more optimal predictors of adverse events in this patient population, such as sarcopenia, or size and character of the psoas or erector spinae musculature.

We recognize several important limitations. First, the retrospective nature of our study carries with it inherent drawbacks, such as an inability to assess variables that were not documented. Although we feel we had an adequate number of patients to perform our primary analysis, we do acknowledge that we had reduced numbers in our sensitivity analyses. These reduced numbers also limited our ability to perform additional analyses of interest. For example, it would be interesting to consider whether HUs might correlate with those spines deemed to be mechanically unstable secondary to osteodiscitis. Such a question would likely require a multi-institutional dataset with larger numbers of patients. Still, the fact that the odds ratios and 95% CIs between HUs and our outcomes did not appreciably differ between the primary and secondary tests is reassuring and demonstrates the resilience of these study findings. Some may suggest that we should have included additional variables in our regression analysis such as albumin, given past literature demonstrating its association to mortality in this patient population [18]. However, albumin levels were unfortunately only available in a minority of our patients. Still, given the absence of an association between HUs and the outcomes of interest, we do not believe that the exclusion of albumin materially impacted our estimations. Although substrate data were collected from patients treated by different providers across 4 institutions, given the reality of our single health system in a specific metropolitan area, there is the prospect for clustering and restricted clinical variation across certain parameters to impact some of our estimations. Nonetheless, given the immutable nature of the effect size, even following sensitivity tests, we do not believe that this concern represents a major issue for our study.

Conclusions

In conclusion, we found no evidence to suggest that vertebral HUs represent a useful prognostic measure for adverse events following treatment of SEA. We believe this result is important, as it contributes to the growing body of literature suggesting that vertebral HUs are specific to bone quality rather than representing an opportunistic marker that is indicative of frailty. Future research involving vertebral HUs likely should restrict their focus to complications mediated by bone quality. Additionally, future research hoping to leverage 3-dimensional imaging as a prognostic tool in the SEA patient population should focus on alternative targets such as sarcopenia, or the appearance of the paraspinal supporting structures.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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