

# A Novel Mangled Upper Extremity Injury Assessment Score

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**Background:** Managing mangled upper extremity injuries is a challenging problem because multiple tissue components including soft tissue, muscle, tendon, bone, nerves, and vessels are involved. The complexity of these injuries has hindered the development of accurate scoring systems and treatment algorithms.

**Methods:** Patients with mangled upper extremities presenting to a metropolitan level 1 trauma center in New York City over a 10-year period were identified. A mangled upper extremity was defined as any injury to  $\geq 3$  tissue components involving the extremity proximal to the digit.

**Results:** The injuries and outcomes of 76 patients were evaluated and used to create a Mangled Upper Extremity Score (MUES). One point was assigned for each of the following injury characteristics: patient age  $>40$ , fasciotomy needed, bony fixation required, bony defect present, revascularization required, crush injury mechanism, degloving or avulsion injury present, and a soft tissue defect  $>50$  cm<sup>2</sup>. The MUES correlated with the number of complications ( $P$ value =  $1.96 \times 10^{-7}$ ) and length of hospital stay ( $P$ value =  $3.95 \times 10^{-7}$ ). Next, a Mangled Extremity Severity Score (MESS) equivalent was calculated for each patient. There was no correlation between the MESS and the number of complications ( $P$ value = 0.92) or length of hospital stay ( $P$ value = 0.35).

**Conclusions:** Existing extremity scoring systems, including the MESS, are not reliable in predicting the success of limb salvage attempts or outcomes of mangled upper extremity injuries. The MUES developed in this study correlates significantly with important outcome measures including the number of hospital complications and length of hospital stay. (*Plast Reconstr Surg Glob Open* 2019;7:e2449; doi: [10.1097/GOX.0000000000002449](https://doi.org/10.1097/GOX.0000000000002449); Published online 26 September 2019.)

Mangled upper extremity injuries present a difficult clinical problem. A mangling injury is caused by a crushing, cutting, or tearing mechanism that injures at least 3 tissue types which may include bone, skin, vasculature, and/or nerves.<sup>1</sup> These injuries are further complicated because mangled upper extremities often result from multiple forces including crush, burst,

compression, and shear. Each of these forces damage tissues in different ways and may lead to a complicated combination of pathological damage.<sup>2</sup> The complexity of these injuries has hindered the development of accurate scoring systems and treatment algorithms, with the result being treatment management individualized by patient and injury pattern.

Upper extremity injuries are often devastating and result in profound functional and psychological impact on patients. Difficulties returning to work and performing the activities of daily living after an upper extremity injury are compounded by the poor quality of currently available upper extremity prosthetics.<sup>3</sup> Studies of functional recovery after mangled upper extremity injuries have demonstrated that salvaging sensate digits, even with only minor restoration of movement, is preferred to using a prosthesis.<sup>4</sup> Therefore, identifying salvageable upper extremities after mangling injuries is critically important for patients.

An accurate initial salvageability evaluation is critical because salvage attempts with a low probability of success that ultimately fail, often after multiple revision surgeries,

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can negatively impact a patient's employment, family, savings, self-image, and/or self-respect.<sup>5</sup> Therefore, it is important to develop a methodology that can accurately identify patients who will benefit from the often complex and lengthy upper extremity salvage process. It is also important to identify patients for whom the salvage process is unlikely to be successful. In those unfortunate cases, judicious early amputation should not be considered a failure, but rather a path to achieving better function for these patients.<sup>2</sup>

Perhaps because mangled upper extremity injuries are relatively rare, even hospitals designated as American College of Surgeons trauma centers might not be prepared to accurately and expeditiously evaluate these complex injuries.<sup>6</sup> In view of the foregoing, this study was designed to develop a Mangled Upper Extremity Score (MUES) to be used in evaluating and managing these injuries. Although several scoring systems exist to assist clinicians in determining whether a lower extremity can be salvaged following a mangling injury, the most widely being the Mangled Extremity Severity Score (MESS), these scoring systems have not been validated for use in mangling upper extremity injuries.<sup>7</sup> Importantly, existing mangled lower extremity scoring systems are not useful in predicting functional outcomes for patients with mangling upper extremity injuries.<sup>8</sup> Without a validated upper extremity injury scoring system, many surgeons may elect to attempt to salvage the injured extremity even where an accurate and objective evaluation of the injury would indicate that such an attempt is unlikely to succeed.<sup>9,10</sup>

Because the emergency room is often where vascularity is assessed, damaged structures are characterized, and a salvageability decision is made; ideally, a mangled upper extremity scoring system should be able to be completed quickly and easily during the initial patient evaluation in the emergency room.<sup>9</sup> Therefore, the MUES scoring system developed by this study includes injury characteristics that can be assessed in an emergency room. The MUES can assist surgeons in accurately and confidently determining whether a patient should undergo salvage procedures or whether timely and judicious amputation is indicated.

## METHODS

### Data Collection

Following institutional review board approval, patients with traumatic mangled upper extremity injuries presenting to a metropolitan level 1 trauma center in New York City were identified. Data were collected over a 10-year period. A mangled upper extremity was defined as any injury to  $\geq 3$  tissue components involving an upper extremity proximal to the digits.<sup>11</sup> At the end of the collection period, 76 consecutive patients with mangled upper extremity injuries had been identified. No patients identified were excluded from the analysis. Patients were included only if their injuries met the strict criteria for the definition of a mangling upper extremity injury.

Patient demographics, comorbidities, injury characteristics, soft tissue injuries, skeletal injuries, muscle/tendon

injuries, vascular status, neurologic status, procedural history, and outcome measures were recorded in a database. This study was reviewed and approved by the institutional review board of the New York University School of Medicine.

### Outcome Measures

The number of complications and length of hospital stay were identified as 2 important recovery indicators of outcome. During treatment, each patient was assigned 1 complication event point for each occurrence of pneumonia, deep vein thrombosis, pulmonary embolism, instance of sepsis, major infection, minor infection, tissue necrosis, wound dehiscence, scar contracture, malunion, nonunion, osteomyelitis, contracture, decreased active range of motion (ROM), decreased passive ROM, muscle or tendon rupture, arterial insufficiency, venous insufficiency, takeback, vascular anastomosis failure, motor extrinsic deficit, motor intrinsic deficit, sensory deficit, or neuroma.

### MUES Scoring and Correlation Analysis

A correlation analysis was used to determine which of the recorded injury variables correlated most strongly with the number of complication events a patient had and the length of the patient's stay.

The injury variables that most significantly correlated with a patient's complications and length of stay were patient age  $>40$  years, fasciotomy needed, bony fixation required, bony defect of  $\geq 2$  cm, revascularization required, crush injury mechanism, degloving or avulsion injury present, and a soft tissue defect  $>50$  cm<sup>2</sup>. For each of the injury variables identified as correlating significantly with recovery outcome measures, the patient was assigned 1 MUES point.

### Calculating MESSs

A MESS was calculated for each patient as previously described by Johansen et al<sup>7</sup> and McNamara et al<sup>12</sup>. The first part of the MESS determines whether there was limb ischemia lasting  $>6$  hours. Next, we assigned a limb ischemia score using the level of arterial damage noted for each patient. Each patient's age score was calculated using MESS criteria. The MESS shock points were assigned using the following system: 0 points if no IV fluids or pRBCs were used, 1 point if just IV fluids were used, and 2 points if both IV fluids and pRBCs were used. Finally, each patient had a mechanism of injury reordered which was used to calculate a MESS injury mechanism score.

### Statistical Analysis

All regressions and mean values are presented with corresponding 95% confidence intervals. A  $P < 0.05$  was considered significant. All data modeling and statistical analysis was performed using GraphPad Prism version 7.00 for Mac OS X, published by GraphPad Software (La Jolla, Calif.; [www.graphpad.com](http://www.graphpad.com)).

The correlation between MUES or MESSs and recovery outcome measures was examined using nonlinear regression analysis. The null hypotheses used for comparison

was a slope of zero indicating no correlation between the selected scoring system and the recovery outcome measure. The goodness of fit of the regression was determined by calculating an  $R^2$  value for each nonlinear regression. Significance was calculated using an exact sum-of-squares  $F$  test.

Sensitivity and specificity of MUES and MESSs for predicting upper extremity salvageability required stratifying the data. This was accomplished by dividing the patients into 3 groups. The first group had successful salvage attempts, the second group had salvage attempted which failed and resulted in amputation, and the third group included patients for whom no salvage was attempted. A 1-way ANOVA with Tukey multiple comparison test was performed to determine whether significant differences in MUES or MESSs existed between the 3 groups. The sensitivity and specificity of the MUES and MESSs for determining whether a mangled upper extremity could be salvaged was calculated using data from the successful salvage and failed salvage groups. A standard 2×2 table was used to calculate the sensitivity and specificity of the 2 scoring systems.

Three critical functional outcome measures were identified for patients following a mangled upper extremity injury. The functional outcome measures were tissue necrosis, passive ROM, and sensory defects. The MUESs for patients with and without changes in these functional outcome measures were determined. A 2-tailed unpaired  $t$  test was used to determine whether differences in the MUESs between groups were significant.

## RESULTS

### Study Patient Characteristics

Seventy-six patients with mangled upper extremities were identified over the 10-year study period. Seventy-eight percent of patients were male, and 22% were female. Their average age was 40 years. The majority (65%) of injuries were the nondominant extremity, and 78% were multi-level injuries. Injury mechanisms included crush (66%), degloving/avulsion (62%), and sharp (34%) mechanisms. Defect coverage required skin grafting in 50% of cases, pedicled flaps in 5% of cases, and microvascular free flaps in 20% of cases. Seventy-six percent of patients required multiple debridements with an average of 4 operative procedures required. Of 46 cases where limb salvage was attempted, 39 (85%) were successful. The average hospital length of stay for patients was 20 days (Table 1).

### MUES Scoring System

The MUES scoring system includes injury variables identified as correlating most significantly with patient outcomes. The MUES assigns 1 point for each of the following injury characteristics: patient age >40 years, fasciotomy needed, bony fixation required, bony defect present, revascularization required, crush injury mechanism, degloving or avulsion injury present, and a soft tissue defect >50 cm<sup>2</sup>. The final MUES is the sum of the points assigned based on the patient's injury characteristics. The maximum possible MUES is 8 points (Tables 2 and 3).

**Table 1. Study Patient Population**

	Count	Percentage of Total Patients (%)
Total patients	76	
Average age (y)	40	
Male patients	59	78
Female patients	17	22
Injury to dominant hand	26	34
Multiple level injury	59	78
Crush injury	50	66
Degloving or avulsion injury	47	62
Sharp injury	26	34
Defect requiring skin grafting	38	50
Defect requiring pedicled flap	4	5
Defect requiring microvascular free flap	15	20
Multiple debridements required	58	76
Average number of operative procedures required	4	
Limb salvage attempted	46	
Limb salvage attempt successful (% of attempts)	39	85
Average hospital length of stay (d)	20	

Seventy-six patients with mangled upper extremity injuries were identified during the 10-year study period. Relevant demographic, injury, and outcome statistics are provided in the table. The average patient age was 40 years, 78% of patients were men, and salvage was attempted in 85% of patients with mangled hand injuries. For the patients included in this study, 19 required a complete amputation and 31 required only partial amputations with salvage of the affected limb still being possible.

**Table 2. Injury Characteristics and Associated Point Values Used to Calculate the MUES**

Injury Characteristics	Present (+1)	Absent (0)
Patient age >40		
Fasciotomy needed		
Bony fixation required		
Bony defect present		
Revascularization required		
Crush injury mechanism		
Degloving or avulsion present		
Soft tissue defect >50 cm <sup>2</sup>		
MUES total		0

The MUES is calculated by taking the sum of the points assigned to each patient based on their injury characteristics.

**Table 3. Radiograph and MUES Calculation for a 34-Year-Old Right-Hand Dominant Male Who Had Fallen onto Subway Tracks and Was Brought to the Emergency Department for Management of Upper Extremity Injury**

Injury Characteristics	Present (+1)	Absent (0)
Patient age >40	0	0
Fasciotomy needed	1	0
Bony fixation required	1	0
Bony defect present	1	0
Revascularization required	1	0
Crush injury mechanism	1	0
Degloving or avulsion present	1	0
Soft tissue defect >50 cm <sup>2</sup>	1	0
MUES total	7	0

On examination, he was found to have a significant left-hand injury involving crush and avulsion mechanisms. Radiograph from trauma assessment is provided. According to the MUES scoring system, the patient received a total of 7 out of 8 points. The patient ultimately required an amputation.

**MUES and MESS Correlation to Recovery Outcome Measures**

MUESs had a significant positive correlation to the number of patient complication events ( $P < 0.0001$ ,  $R^2 = 0.31$ ; Fig. 1A), number of operations required ( $P < 0.0001$ ,  $R^2 = 0.35$ ; Fig. 1C), and hospital length of stay ( $P < 0.0001$ ,  $R^2 = 0.30$ ; Fig. 1E). Patients with higher MUESs had significantly more complications, more operations, and longer hospital stays. MESSs, however, did not have a significant correlation to the number of patient complication events ( $P = 0.92$ ,  $R^2 = 0.00$ ; Fig. 1B), number of operations required ( $P = 0.61$ ,  $R^2 = 0.00$ ; Fig. 1D), or hospital length of stay ( $P = 0.35$ ,  $R^2 = 0.85$ ; Fig. 1F).

**MUES and MESS Sensitivity and Specificity for Determining Salvageability**

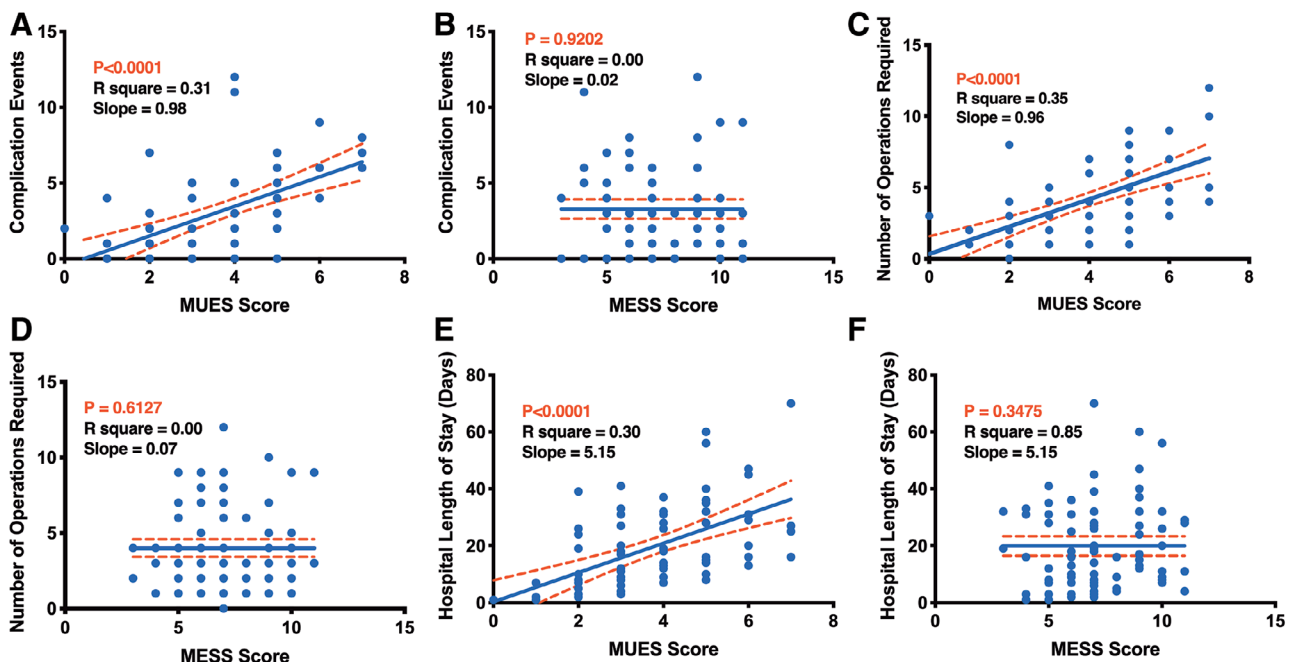
MUESs were significantly greater for patients for whom limb salvage was attempted but was unsuccessful compared with the MUESs for patients for whom limb salvage was attempted and was successful ( $P = 0.04$ ). The mean MUES for patients for whom salvage was attempted and was successful was 3.89. This is compared with a mean MUES for patients for whom salvage was attempted but was unsuccessful of 5.29 (Fig. 2A). There was no significant difference in MESSs between patients with failed limb salvage procedures and patients with successful limb salvage procedures ( $P = 0.88$ ). The mean MESS for patients

with successful salvage attempts was 6.92. For patients with failed salvage attempts, the mean MESS was 7.29 (Fig. 2B).

The sensitivity and specificity of the MUES for detecting the futility of upper extremity limb salvage procedures, using a MUES salvage threshold score of  $\geq 6$ , was 43% and 82%, respectively (Fig. 2C). The sensitivity and specificity of the MESS, using a MESS salvage threshold score of  $\geq 7$ , for detecting the futility of an upper extremity limb salvage procedure was 71% and 36%, respectively (Fig. 2D).

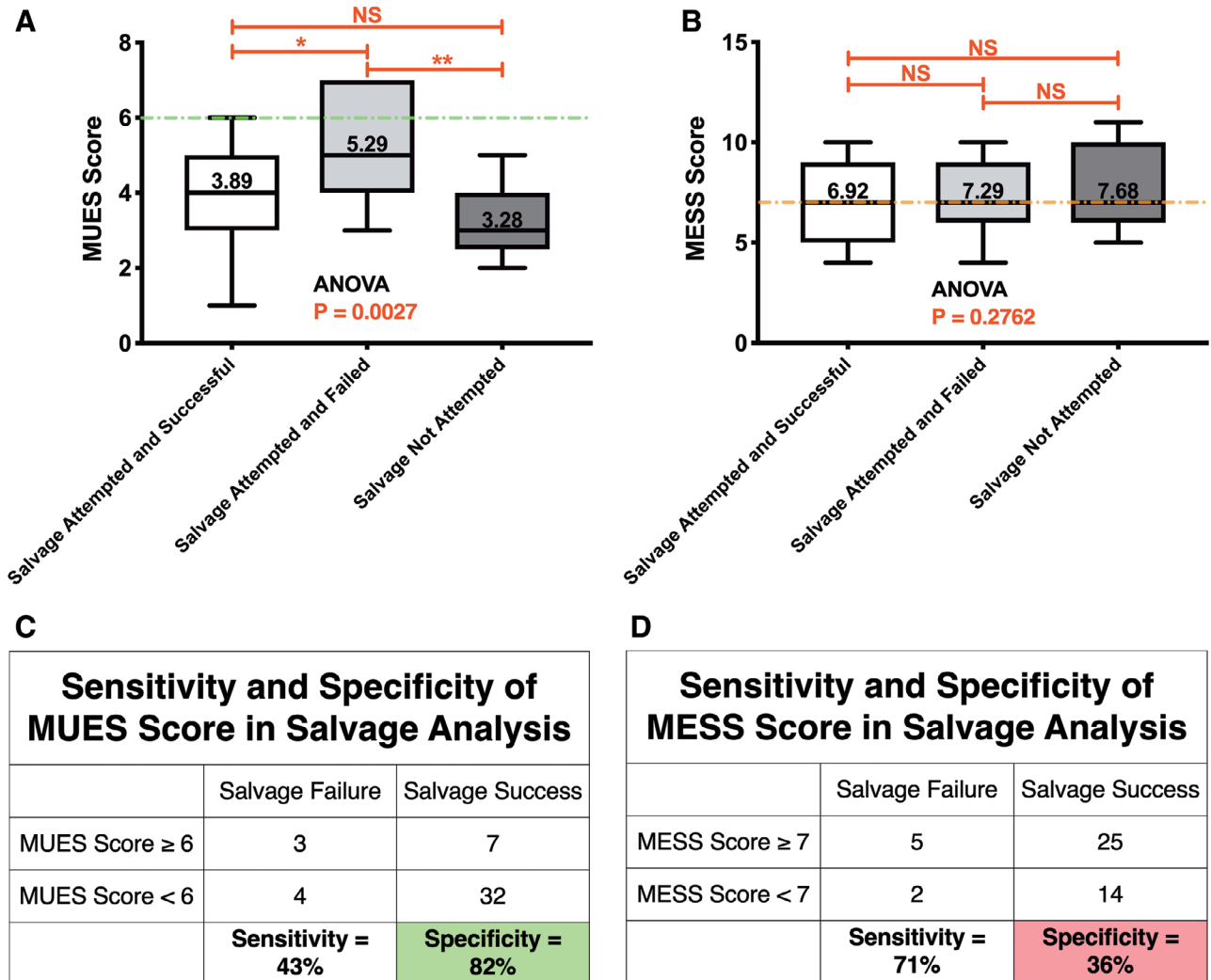
**MUESs Related to Functional Outcomes**

Patients who had additional tissue necrosis on the affected upper extremity during the recovery period had significantly higher MUESs. The mean MUES for patients with no tissue necrosis was 3.60, compared with a mean MUES of 4.50 for patients who had tissue necrosis ( $P = 0.02$ ; Fig. 3A). Similarly, the mean MUES was higher in patients who did not recover full passive ROM after a mangling upper extremity injury. The mean MUES for patients with normal passive ROM was 3.77, compared with a mean MUES of 4.48 in patients who had decreased passive ROM ( $P = 0.04$ ; Fig. 3B). Patients who had sensory defects following a mangled upper extremity injury had significantly higher MUESs compared with those patients who recovered with normal sensation. The mean MUES for a patient who recovered normal sensation was 3.74, compared with a mean MUES of 4.68 in patients who had a sensory defect remaining ( $P = 0.01$ ; Fig. 3C).



**Fig. 1.** MUESs correlate significantly with recovery outcome measures in patients with mangled upper extremity injuries. (A–F) Patient MUESs and MESSs plotted against number of complication events, operations required, or hospital length of stay. A solid blue nonlinear regression line is provided on each graph depicting the relationship between the respective scoring system and the outcome measure of interest. The dashed red lines above and below the regression line represent the 95% confidence interval for the regression. There are significant positive correlations between the MUESs and the outcomes of interest. No significant correlation is noted between MESSs and the outcomes of interest.





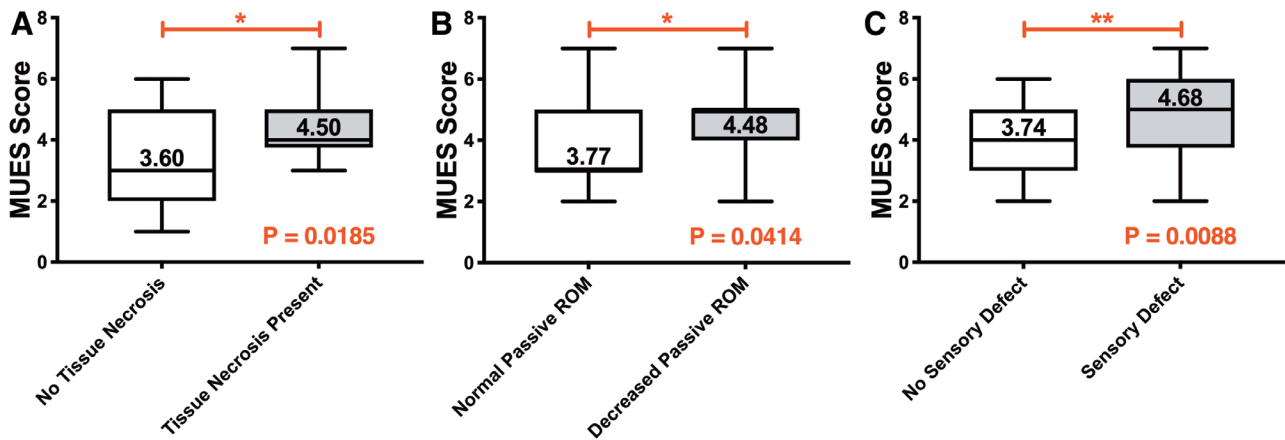
**Fig. 2.** MUESs are significantly higher for patients where limb salvage failed compared with patients where limb salvage was successful. (A, B) The mean MUESs and MESSs are shown for 3 groups of patients: successful salvage, failed salvage, and no salvage attempted. Additionally, the whiskers of the box plot depict the 95% confidence intervals for each group’s MUES or MESS. On the MUES graph, a dashed green line depicts the recommended MUES salvage threshold score of  $\geq 6$ . The average MUES for failed salvage attempts was 5.29 compared with 3.89 when salvage was successful. On the MESS graph, a dashed orange line represents the previously published recommended MESS salvage threshold score of  $\geq 7$ . MESSs did not differ significantly between patients with failed compared with successful salvage attempts. The average MESS was 7.29 for failed salvage attempts and 6.92 when salvage was successful. (C) Table (2  $\times$  2) used to calculate sensitivity and specificity of MUES test for predicting when mangled upper extremity salvage attempts will fail. The specificity of the test is shaded in green. (D) Table (2  $\times$  2) used to calculate sensitivity and specificity of MESS test for predicting when mangled upper extremity salvage attempts will fail. The specificity of the test is highlighted in the box shaded in red.

### DISCUSSION

Treating mangled upper extremities is complicated and challenging. Damage to multiple tissues types in mangling injuries makes assessing the extent of injury and salvageability difficult. Despite this, determining whether a mangled upper extremity can be salvaged is a critical decision for a surgeon. This determination is important because the timely and judicious amputation of a mangled upper extremity can provide better functional outcomes compared with undergoing multiple failed attempts trying to salvage an unsalvageable upper extremity. In addition, significantly lower rates of infection are observed when wounds from mangled extremity

injuries have soft tissue coverage within 72 hours.<sup>9</sup> For these reasons, a scoring system that accurately and quickly predicts whether a mangled limb can be successfully salvaged would reduce the incidence of potentially devastating infections in recovering patients and improve functional outcomes.

By analyzing injury patterns, management, and outcomes in a large sample of patients with mangled upper extremity injuries, this study developed a MUES that can guide the management of complicated upper extremity injuries. The reliability of the developed MUES is significant because the patient demographics of our study population is consistent with the types of patients who most



**Fig. 3.** Higher MUESs were seen in patients with worse functional outcomes following a mangled upper extremity injury. (A–C) The mean MUESs are given for patients who had tissue necrosis, decreased passive ROM, or decreased sensation following a mangled upper extremity injury compared with patients without these postsalvage functional limitations. The whiskers of the box plots depict the 95% confidence intervals for each group's MUES. An unpaired 2-tailed *t* test was performed comparing the 2 groups, and the associated *P* value is provided. MUESs were significantly higher in patients with decreased functional outcomes after salvage.

commonly present with mangled upper extremity injuries. The majority of mangling upper extremity injuries occur in men. Rosberg et al<sup>13</sup> reported that in reviewing 2,188 patients referred to their surgery department with hand injuries, almost 70% were men. In this study, 78% of the patients were men.

Existing extremity scoring systems, including the MESS, have not been reliable in predicting the success of limb salvage or outcomes of mangled upper extremity injuries. This is likely due to the significant anatomic and physiologic differences between upper and lower extremities. These differences include upper extremities having a smaller muscle mass than lower extremities. As a result, the factors contributing to the development of crush syndrome after a mangling injury of an upper extremity are less pronounced than of a lower extremity.<sup>10</sup> Additionally, although injury to the popliteal artery in the lower extremity can lead to significant ischemia, there is no analogous artery in the upper extremity.<sup>14</sup> The decreased muscle mass and more dispersed collateral circulation in upper extremities are important reasons why the MESS scoring system does not accurately evaluate mangled upper extremity injuries.

The scoring system developed by this study is specific for mangled upper extremities. The study analyzed the largest available collection of recorded data on mangled upper extremity patients. Injury patterns, management, and outcomes were examined, and the key injury characteristics that correlated most strongly with patient outcomes and, therefore, should be included in a mangled upper extremity injury assessment scoring system were identified. The results of this analysis were used to develop the MUES. Patient MUESs significantly correlated with important hospital and functional outcome measures including the number of hospital complications and the length of the hospital stay. The developed MUES scoring system will help clinicians determine which patients should have limb salvage attempted.

The MUES scoring system developed in this study assigns 1 point for each of the following injury characteristics: patient age >40 years, fasciotomy needed, bony fixation required, bony defect present, revascularization required, crush injury mechanism, degloving or avulsion injury present, and a soft tissue defect >50 cm<sup>2</sup>. These patient and injury variables had the most significant correlations to patient outcomes. Identifying these variables is consistent with studies that suggest that when evaluating upper extremity mangling injuries, more tissue damage results from crush and avulsion injuries. This suggests that a worse functional prognosis is likely with crush and avulsion mechanisms compared with sharp or guillotine-type injuries.<sup>4</sup> Additionally, in other studies, the combination of soft tissue and skeletal injuries has consistently been the strongest statistical predictor of a need for extremity amputation.<sup>12</sup>

This study confirmed that the existing MESS scoring system is a poor predictor of recovery outcomes for patients with mangled upper extremity injuries. MESSs did not show any significant correlation to the number of complications, operations required, or length of hospital stay for patients with mangled upper extremity injuries. In contrast, the MUES developed in this study showed significant correlations to these important recovery outcomes (Fig. 1A, C, and E). Additionally, MUESs were significantly higher in patients who had poor extremity functional outcomes after a mangled upper extremity injury (Fig. 3). Because the MUES correlates to recovery and functional outcomes, surgeons can be confident in using the MUES scoring system in the acute setting to evaluate the salvageability of mangled upper extremities.

In previous studies a MESS  $\geq 7$  has been used to indicate that amputation is preferred over salvage attempts.<sup>5</sup> However, when applied to the upper extremity, the specificity for this test is only 36%. With a specificity this low, using the MESS scoring system to evaluate upper extremities would lead to many patients undergoing amputa-

tion despite having a good chance of success if salvage was attempted. The MUES developed in this study had a specificity of 82% in cases where a patient had a score of  $\geq 6$  (Fig. 2A, C). Because the MUES scoring system has a relatively high specificity, surgeons can be confident that when an upper extremity amputation is indicated with a MUES  $\geq 6$ , there is little chance of a salvage procedure succeeding.

Shanmuganathan<sup>5</sup> suggests that salvage threshold scores used with a scoring system designed to evaluate mangled upper extremities should be adjusted based on treatment center's salvage capabilities. Therefore, the MUES proposed by this study should be used as a platform and starting point for centers to determine and regularly evaluate their threshold for when mangled upper extremity salvage attempts are warranted and when judicious early amputation would result in a better outcome for a patient. MUESs can also help patients to better understand the risk of complications associated with limb salvage procedures.

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