Upper-Extremity Function Predicts Adverse Health Outcomes among Older Adults Hospitalized for Ground-Level Falls

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Keywords

Frailty · Discharge disposition · Readmission · Inpatient care · Trauma · Fall incident · Wearable technology · Functional test · Bedbound patients · Inpatient triage

Abstract

Background: Despite National Surgical Quality Improvement guidelines to integrate frailty into surgical elder assessments, a quick, accurate, and simple frailty assessment tool suitable for busy clinical settings is still not available. Recently, we have demonstrated that a simple upper-extremity function (UEF) test based on wearable sensors could identify frailty with high agreement with conventional assessments by testing 20-s repetitive elbow flexion and extension. **Objective:** We examined whether UEF parameters are sensitive for predicting adverse health outcomes in bedbound older adults admitted to hospital due to ground-level fall injuries. **Study Design:** Frailty was assessed in 101 eligible older adults (age: 79 ± 9 years) admitted to a trauma setting using the UEF test at the time of admission. All participants were followed up for 2 months using phone calls and chart reviews. The measured health outcomes included (1) dis-

charge disposition (favorable: discharge home or rehabilitation; unfavorable: discharge to skilled nursing facility or death), (2) hospital length of stay, (3) 30-day readmission, (4) 60-day readmission, and (5) 30-day prospective falls. Multivariate analyses were used to identify independent predictors of adverse health outcomes based on participants' demographic parameters (i.e., age, gender, and body mass index [BMI]) and UEF index. **Results:** Based on the UEF frailty status, 53 (52%) of the participants were frail and 48 (48%) were non-frail. Among all adverse health outcomes, age was only a significant predictor of 30-day prospective falls ($p = 0.023$). On the other hand, the UEF index was a significant predictor of all measured outcomes except hospital length of stay ($p < 0.010$). Among the UEF parameters, those indicating slowness, weakness, and exhaustion had the highest effect sizes to predict an unfavorable discharge disposition ($p < 0.010$; effect size = 0.65–0.92). **Conclusion:** The results of this study suggest that a 20-s UEF test is practical in the

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trauma setting and could be used as a quick measure for predicting adverse events and outcomes among bedbound patients after discharge. Assessing frailty using UEF may assist in objective triage, treatment, and post-discharge decision-making with regard to geriatric trauma patients.

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Introduction

Falls and fall-related injuries are significant health and safety problems for older adults. Nearly 30% of community dwellers over the age of 65 years experience 1 or more falls every year, leading to a significant risk for hospitalization, institutionalization, and even death [1]. Of older adults who are hospitalized for falls, only half survive, and the other half succumb to the trauma a year later [2]. Although age is strongly associated with adverse health outcomes due to traumatic falls, the response of an older adult to traumatic events, hospitalization, treatment, and rehabilitation is highly variable due to the heterogeneity of aging [3]. To account for this variation, risk stratification using a measure of physiological function is required. Recently, measures of frailty have been used to predict low physiological functional reserve and high vulnerability to poor outcomes [4, 5].

We previously developed an objective method for assessing frailty based on upper-extremity function (UEF) and validated this test among trauma patients with convergence to the Trauma-Specific Frailty Index (TSFI) [6, 7]. The UEF test incorporates several frailty features. With UEF, the strength of upper-extremity muscles in performing a rapid task can be measured, thereby resembling the grip strength test. Also, the theorized biological mechanism is that sarcopenia/dynapenia, as a manifestation of physical frailty, would influence the entire muscular structure of the human body, including both the lower and the upper extremities [4, 8]. Therefore, speed of upper-extremity movement was measured as a surrogate for gait speed. The UEF assessment method integrates low-cost sensors, the physical task (elbow flexion) is easily performed in under 1 min, and the postprocessing is performed in less than 2 min.

In a recent validation study among 101 trauma patients (≥ 65 years), the UEF index was developed to include speed of elbow flexion (slowness), elbow power (weakness), and speed reduction (exhaustion) in a repetitive 20-s elbow flexion test [7]. The purpose of the current prospective study was to assess the validity of the previously developed UEF index (based on the TSFI) in

predicting in-hospital and post-discharge health outcomes in 101 older adult patients (aged ≥ 65 years) admitted for ground-level falls to a southwestern academic integrated health care system level I trauma center. We hypothesized that the UEF index would be significantly associated with discharge disposition, readmission, and prospective falls.

Subjects and Methods

Participants

Older adults with ground-level fall injuries were recruited (January 2014 to August 2015) from the Division of Trauma, Critical Care, Burn and Emergency Surgery service at the University of Arizona. A fall was defined as an incident in which a participant unintentionally came to rest on a lower surface [9, 10]. The inclusion criteria were (1) being aged 65 years and older, (2) possessing the ability to understand the study instructions for performing repetitive elbow flexion, and (3) having had at least 1 ground-level fall causing an injury within the prior 2 weeks that led to hospital admission. Participants were excluded if they had significant upper-extremity disorders in both arms (e.g., bilateral fractures or rheumatoid arthritis with elbow or shoulder involvement), or if they were in a physical condition (e.g., such as severe head injury and unconsciousness) that precluded them from performing the UEF test. Participants were not screened for cognition, since cognitive impairment is a common comorbidity among older adults and is associated with falls and adverse health outcomes [11–13].

The study was approved by the University of Arizona Institutional Review Board. Written informed consent was obtained by trained research coordinators according to the principles expressed in the Declaration of Helsinki [14] from all participants, or from their authorized health care power of attorney if a participant was clinically assessed as lacking capacity for informed consent.

Health Outcome Assessment

All participants were followed up for 2 months using monthly phone calls and chart reviews. The measured health outcomes included (1) discharge disposition (favorable: discharge home or rehabilitation; unfavorable: discharge to skilled nursing facility or death), (2) hospital length of stay, (3) 30-day readmission, (4) 60-day readmission, and (5) 30-day prospective falls. Readmission and fall events were assessed from the day of discharge. Of note, all readmissions to the same center or other centers due to trauma and falls were recorded. Further, 30- and 60-day readmission and 30-day prospective fall events were confirmed by a relative or an authorized caregiver in case participants were not able to recall them. Additionally, comorbid conditions were recorded, including hypertension, stroke, blood dyscrasia, hypercholesterolemia, cirrhosis, chronic obstructive pulmonary disease, history of cancer, use of immunosuppressive medications, autoimmune disorders, coronary artery disease, dementia, and chronic renal failure. The injury severity score (ISS) and the Abbreviated Injury Scale (AIS) score were also recorded to assess the severity of injury.

Table 1. Definitions of UEF parameters

Parameter	Definition
Speed	Mean value of the elbow angular velocity range (maximum minus minimum speed)
Flexibility	Mean value of the elbow flexion range
Power	Mean value of the product of the angular acceleration range and the range of angular velocity
Rise time	Mean value of the time required to reach maximum angular velocity
Moment	Mean value of the maximum moments on the elbow within each flexion/extension estimated from the moment of inertia of the forearm and hand, and elbow motion
Speed variability	Coefficient of variation (standard deviation divided by the mean) of the angular velocity range
Speed reduction	Difference in angular velocity range between the last and the first 5 s of elbow flexion as a percentage of the initial angular velocity range
Flexion number	Number of flexions/extensions during 20 s

Of the UEF parameters, speed, power, and speed reduction were used to develop the UEF index. UEF, upper-extremity function.

UEF Assessment and Index

Per our previously validated method [15], wearable sensor technology was used to measure forearm and upper-arm motion. A triaxial wearable gyroscope sensor (dynamic range: $\pm 2,000^\circ/\text{s}$; sample frequency: 100 Hz; BioSensics LLC, Boston, MA, USA) was attached to the upper arm near the biceps, and one to the wrist, using a band attached with Velcro, to estimate 3-dimensional angular velocity of the upper-arm and forearm segments, and ultimately elbow angular velocity. Each participant performed an approximately 20-s trial of elbow flexion, within which they repetitively flexed and extended their dominant elbow to full flexion and extension as quickly as possible in supine (bedbound) position while wearing the UEF system. Participants performed the elbow flexion task with their nondominant side in the case of injury or attachments of vital sign-monitoring equipment. Before the actual test, participants performed a short practice trial to become familiar with the protocol. The protocol was explained to the participants, and they were encouraged only once, before elbow flexion, to do the task as fast as possible (they were encouraged no further during the task). All UEF assessments were performed by trained researchers (N.T., M.R.H., and T.O.J.) during the participants' hospital stay.

Several outcome measures representing kinematics and kinetics of elbow flexion were derived using angular velocity and anthropometric data (i.e., the participants' stature and body mass). The outcome measures included (1) speed, (2) flexibility, (3) power, (4) rise time, (5) moment, (6) speed variability, (7) speed reduction, and (8) flexion number (see Table 1 for definitions) [15]. The UEF index represents the continuous frailty index and categorical frailty status (i.e., non-frail and frail) based on the UEF parameters and has been validated using a modified Rockwood questionnaire, the TSFI [6]. The results from the validation study showed a high agreement ($r = 0.72$, $p < 0.0001$) between TSFI score and UEF model; sensitivity and specificity for predicting the frailty status were 78 and 82%, respectively, compared to the TSFI as the gold standard. Readers are referred to previous work [7, 15] for more details regarding the validation of

UEF using a motion capture system, and for a detailed description of parameter calculations and UEF index development. Briefly, the UEF index is a 0-to-1 score (0 = minimum frailty symptoms; 1 = maximum frailty symptoms), and those with a score of ≤ 0.27 are considered non-frail (those with a score of > 0.27 are frail). Of note, only speed, power, and speed reduction (reduction in angular velocity within 20 s) were used to develop the UEF index, as they showed the best associations with the TSFI. These parameters, respectively, represent "slowness," "weakness," and "exhaustion" frailty markers.

Statistical Analysis

Between-group differences in demographic information and adverse health outcomes for the frailty groups (i.e., non-frail: UEF index ≤ 0.27 ; frail: UEF index > 0.27) were determined using analyses of variance (ANOVAs) and Cohen's effect sizes were calculated [16]; statistical analyses were adjusted for age, gender, and BMI for comparisons of adverse health outcomes between the frailty groups. Further, separate models of logistic regression (for nominal health outcomes) and ANOVA regression (for continuous health outcomes) were used to determine the association between the UEF index (as one of the independent variables) with each of the health outcomes (as a dependent variable); all regressions were adjusted for age, gender, and BMI (a total of 5 models).

Statistical analyses were adjusted for age, gender, and BMI to account for possible influences of these parameters on health outcomes. For those adverse health outcomes that showed a significant association with the UEF index, we performed further statistical analyses to determine the association between individual UEF parameters with each of the adverse health outcomes. For this purpose, the UEF parameters were compared between 2 groups (with positive or negative health outcomes) using separate ANOVAs with age, gender, and BMI as covariates. To account for the effect of discharge disposition (favorable vs. unfavorable) on the results, additional logistic regression models were developed to associate the UEF index with 30- and 60-day readmission and 30-day prospective falls, adjusting for age and discharge disposition. All anal-

Table 2. Demographic data and health outcome measures for the frailty groups as defined by the UEF test

Variable	Non-frail group	Frail group	<i>p</i> value ^a	Lower CI	Upper CI	Effect size
Number, <i>n</i> (% of total)	48 (48)	53 (52)	–	–	–	–
Mean UEF index (SD)	0.18 (0.05)	0.39 (0.10)	–	–	–	–
Male, <i>n</i> (% of the group)	26 (54)	21 (40)	0.143	–0.10	0.69	–
Mean age (SD), years	76 (9)	81 (9)	0.004*	0.88	4.39	0.56
Mean stature (SD), cm	168.32 (9.41)	166.48 (10.36)	0.360	–2.91	1.07	0.19
Mean body mass (SD), kg	72.72 (15.14)	68.84 (15.98)	0.221	–5.06	1.18	0.25
Mean BMI (SD)	25.55 (4.40)	24.74 (4.84)	0.388	–1.33	0.52	0.18
Unfavorable discharge disposition, <i>n</i> (% of the group)	8 (17)	24 (45)	0.003*	0.25	1.32	–
Mean hospital length of stay (SD), days	4.44 (2.98)	5.85 (5.31)	0.200	–0.33	1.54	0.33
30-day readmission, <i>n</i> (% of the group)	10 (21)	19 (36)	0.136	–0.85	0.11	–
60-day readmission, <i>n</i> (% of the group)	15 (31)	28 (53)	0.097	–0.80	0.07	–
30-day prospective falls, <i>n</i> (% of the group)	5 (10)	16 (30)	0.049*	–1.14	0.04	–

UEF, upper-extremity function. * Significant between-group difference.

^a *p* values for between-group differences in adverse health outcome measures are adjusted for age, gender, and BMI.

Table 3. Comorbidity measures for the frailty groups as defined by the UEF test

Comorbidities	Non-frail group, % (<i>n</i> = 48)	Frail group, % (<i>n</i> = 53)	<i>p</i> value
Hypertension	60	92	<0.001*
Hyperlipidemia	43	56	0.056
Coronary artery disease	25	46	0.001*
Stroke	4	13	0.018*
Dementia	23	45	<0.001*
Cirrhosis	<1	1	0.436
Chronic renal failure	8	7	0.546
Chronic obstructive pulmonary disease	3	18	<0.001*

UEF, upper-extremity function. * Significant between-group difference.

Table 4. Injury details for the frailty groups as defined by the UEF test

Variable	Non-frail group (<i>n</i> = 48)	Frail group (<i>n</i> = 53)	<i>p</i> value
Mechanism, %			
Blunt injury	96	96	0.608
Fall	53	68	0.020*
Motor vehicle collision	40	26	0.022*
ISS	10 (10–14)	10 (9–14)	0.220
Head-AIS score	2 (2–3)	2 (2–3)	0.082
Thorax-AIS score	3 (2–3)	3 (2–3)	0.550
Abdomen-AIS score	2 (2–2)	2 (1–2)	0.124
Extremity-AIS score	2 (2–3)	2 (1–2)	0.123

Values for the ISS and AIS are medians (interquartile ranges) of the injury scores. ISS, injury severity score; AIS, Abbreviated Injury Scale. * Significant between-group difference.

yses were performed using JMP™ (version 11; SAS Institute Inc., Cary, NC, USA), with a significance level of *p* < 0.05. Summary results are presented as means with standard deviation (SD) and standard error (SE).

Results

Participants

A total of 101 older adults were recruited for the current study. Based on the UEF frailty status, 53 (52%) of

the participants were frail and 48 (48%) were non-frail. The mean (SD) age and BMI of the frail participants were 81 (9) years and 24.74 (4.84); the corresponding values were 76 (9) years and 25.55 (4.40) for the non-frail participants. Of the demographic parameters, only age was significantly different between the UEF-defined non-frail and frail groups (*p* = 0.004). Other sociodemographic data are reported in Table 2. Overall, frail participants were more likely to have pre-existing comorbid conditions than non-frail patients. Table 3 provides a comparison of several pre-existing comorbidities between the

Table 5. Association between the UEF index and prospective health outcomes

Independent variable	Dependent variable	Parameter estimate ^a	χ^2 or t ratio	p value	Lower CI	Upper CI
UEF index (0–1)	Unfavorable discharge disposition	9.23	14.58	<0.001*	4.84	14.40
Age (years)		0.01	0.07	0.794	–0.05	0.07
Gender (female)		0.15	0.31	0.578	–0.38	0.68
BMI		0.04	0.45	0.498	–0.07	0.15
UEF index (0–1)	Hospital length of stay	4.16	1.14	0.256	–3.06	11.37
Age (years)		0.02	0.41	0.681	–0.08	0.12
Gender (female)		–0.27	–0.56	0.576	–1.21	0.68
BMI		–0.14	–1.41	0.162	–0.34	0.06
UEF index (0–1)	30-day readmission	4.88	6.65	0.008*	1.28	8.78
Age (years)		0.01	0.06	0.808	–0.05	0.06
Gender (female)		–0.32	1.71	0.186	–0.82	0.15
BMI		–0.01	0.01	0.939	–0.11	0.10
UEF index (0–1)	60-day readmission	4.44	6.11	0.010*	1.04	8.14
Age (years)		0.02	0.92	0.345	–0.02	0.07
Gender (female)		–0.21	0.84	0.356	–0.67	0.23
BMI		0.01	0.01	0.935	–0.09	0.10
UEF index (0–1)	30-day prospective falls	5.55	6.23	0.010*	1.31	10.14
Age (years)		0.07	4.47	0.023*	0.01	0.14
Gender (female)		–0.56	3.42	0.056	–1.18	0.01
BMI		–0.11	2.39	0.103	–0.25	0.02

Independent variables for each regression analysis included the UEF index, age, gender, and BMI. UEF, upper-extremity function. * Significant independent association. ^a Parameter estimates for nominal health outcomes are presented for log odds of adverse event presence/absence.

groups. Blunt injury was the predominant mechanism of injury in our population. Frail participants were more likely to present with falls than non-frail patients ($p = 0.02$). Table 4 elaborates the comparison of injury patterns and severity.

Association between UEF and Adverse Health Outcomes

As indicated in Table 2, the percentage of participants who had adverse prospective health outcomes following their hospital stay was greater in the frail than in the non-frail group as defined by UEF; differences were significant for the rates of an unfavorable discharge disposition and prospective falls within the 30-day follow-up period ($p < 0.049$). Further, when adjusted for sociodemographic data, the UEF index was a significant predictor of all adverse health outcomes ($p < 0.010$) except of hospital length of stay (Table 5); specifically, the UEF index was a strong predictor of an unfavorable discharge

disposition ($p < 0.001$) and readmission ($p < 0.010$). When the logistic models were adjusted for discharge disposition (in addition to age), the UEF index remained a significant predictor of 30- and 60-day readmission and of 30-day prospective falls ($p < 0.03$). Of importance, chronological age itself was significantly associated with a single adverse outcome, i.e., prospective falls ($p = 0.02$; Table 5).

The ANOVA analyses revealed that all 3 UEF index parameters (i.e., speed, power, and speed reduction) were significantly different between individuals who had an unfavorable discharge disposition and those who had not ($p < 0.010$; effect size = 0.65–0.92; Fig. 1). The ANOVA results for the other adverse health outcome measures, including 30- and 60-day readmission and 30-day prospective falls, showed that only the speed reduction parameter was consistently worse among participants who had adverse health outcomes following hospitalization ($p < 0.03$; effect size = 0.42–0.65).

Fig. 1. Differences in the UEF parameters of slowness (a), weakness (b), and exhaustion (c) between participants who had a favorable and those who had an unfavorable discharge disposition following their hospital stay. * Significant difference.

Discussion

UEF and Frailty

Although several researchers have focused on identifying frailty, assessing frailty is still controversial [17]. Two common methods for defining frailty are (1) the Fried categorical index, based on a specific phenotype of 5 criteria (weight loss, exhaustion, low physical activity, weak grip strength, and slow walking speed), and (2) the Rockwood frailty index, based on a count of 70 accumulated deficits, including the presence and/or severity of diseases, ability in activities of daily living, and physical signs from clinical and neurological examinations [4, 5]. Among more than 2,000 older adults (≥ 70 years), previous work showed that the 2 measures of Fried and Rockwood were moderately correlated ($r = 0.65$) [5].

The UEF test was initially developed and validated using the “gold-standard” Fried index among community-dwelling older adults. We subsequently validated the test based on the TSFI among trauma patients, and we developed a trauma-specific index. Since approximately 50% of the trauma patients were not able to walk at the time of measurement, the Fried test was not performed in this trauma setting [7]. Furthermore, the UEF test was validated in a separate study among trauma patients (in addition to community-dwelling older adults) to account for possible differences in function due to injury severity and medications. Overall, a worse UEF performance was observed among hospitalized compared to nonhospital-

ized community-dwelling participants [15] when adjusted for age, gender, and BMI. For instance, speed was around 30% reduced and the speed reduction was approximately 60% larger among trauma patients ($p < 0.02$).

UEF and Discharge Disposition

As hypothesized, within the current sample of hospitalized older adults who had a ground-level fall, prospective post-discharge adverse health outcomes were significantly associated with frailty as measured using the UEF index. Among all prospective adverse health outcomes, the strongest association was observed between UEF and unfavorable discharge disposition. Previous studies on trauma patients revealed that the Rockwood 50-item frailty index (which includes comorbidities, daily activities, health attitude, function, and nutrition factors) is a strong predictor of unfavorable discharge disposition, independent of age [18]. To date, to the best of our knowledge, no other study has utilized admission frailty measures for predicting discharge disposition among ground-level injury or any type of trauma patients. In other clinical research, AIS, ISS, and the Glasgow Coma Scale (GCS) have been commonly used as predictors of post-hospitalization outcomes among trauma patients, with weak correlations ($r < 0.34$) between these injury measures and prospective adverse health outcomes [19, 20]. Of note, all previously implemented methods for assessing prospective adverse health outcomes in trauma patients, including frailty and injury severity assessments,

involve subjective questionnaires. To the best of our knowledge, the current study is the first proposing a method for objective physical frailty assessment of geriatric trauma patients.

Among older hospitalized adults with nontraumatic injuries, several researchers have reported a significant association between frailty and discharge disposition after surgery [21–23]. Commonly implemented assessments in these studies include measures of activity of daily living (e.g., Katz score), comorbidity (e.g., Charlson comorbidity index), function (e.g., gait speed and Timed Up and Go test), nutrition (e.g., albumin level), cognition (e.g., Mini-Cog test), and geriatric syndromes (e.g., falls), as well as social factors. Of all these factors, functional measures of frailty have been shown to be more closely associated with the need for post-discharge institutionalization [22, 23]. Performing common frailty function measures such as the gait and Timed Up and Go tests is, however, impossible for most bedbound patients with traumatic injuries, and subjective questionnaires are often time-consuming. Accordingly, Goldstein et al. [24], in a review of frailty measures in emergency medicine settings, highlighted the fact that although the utility of measuring frailty is clear, a practical measure of frailty is lacking. The current study focused on validating an objective, rapid method for prospective adverse health outcome evaluation which is easily performed in the acute care setting.

UEF and Readmission

The readmission rate is often considered a measure of quality of care. Due to the recent congressional enactment of a Medicare Hospital Readmissions Reduction Program, American hospitals are now penalized for 30-day readmissions [25]. Our findings show that while age was not significantly associated with readmission, frailty may, to some extent, predict 30-day and 60-day readmission among older trauma patients. Similar to discharge disposition assessments, there are a limited number of studies regarding readmission prediction among trauma patients. In a recent study, Housley et al. [26] used pre-injury medications and comorbidities to assess frailty in trauma patients. Within a large sample of 879 trauma patients, they demonstrated that frailty is a significantly stronger predictor of readmission than age. Several studies have recently been published that show the association between frailty and readmission rates among non-trauma older adults, including heart and elective surgery patients.

Among approaches implemented for assessing frailty, the Fried [27–30] and Rockwood [31, 32] indices are the

most common tools. Overall, the Fried index, which involves functional measures in addition to subjective questionnaires, provides better predictions of readmission than the Rockwood score. Within the current study, a significant difference in UEF index was also observed between those who were readmitted to hospital and those who were not ($p < 0.010$; effect size = 0.57 and 0.64 for 30- and 60-day readmission, respectively). Overall, the current findings and the previous literature suggest that frailty assessment may provide a promising tool for identifying older adults with a higher chance of readmission among those in acute and outpatient care.

UEF and Falls

The UEF index was associated with both prospective falls (current results) and retrospective falls within the prior year [7]. Although several previous studies have associated fall risk with lack of strength and function in lower-extremity muscles [33–37], the current findings suggest that UEF may also be related to higher rates of falls. This observation suggests that this lack of strength or function seen in older adults may be systematic and related to the dynapenia and sarcopenia seen with aging, influencing both lower- and upper-extremity performance. This hypothesis is in agreement with previous studies that revealed associations of upper-body and lower-extremity muscle strength with fall risk [34, 35].

Predicting those who are at higher risk of falling would have important financial and health care benefits. In previous research, poor balance and fall risk were related to lack of physiological reserve and frailty among older adults [4, 37–39]. However, measuring frailty in those who are at higher risk of falling, especially in older adults who are admitted for fall injuries, still requires further research. The use of new, objective technology may play a substantial role in enhancement of frailty assessment. Although our current findings require further confirmation in larger samples, they show promise for a practical implementation of wearable sensor technology and UEF for fall assessment in an outpatient setting.

Limitations

First, as with measurement limitations in gait-based frailty measures, upper-extremity disability or injury may limit measurements; we found this to be the case for some individuals, who were excluded from the study because they were unable to perform the UEF task. That said, it is likely that this limitation would also apply to measuring grip strength, which would likewise limit measurements within the Fried index. Furthermore, due to upper-ex-

tremity attachment of vital sign-monitoring equipment within the hospital setting, 32 (32%) of the participants were not able to perform the UEF test on their dominant arm; thus, the assessment was performed using the non-dominant arm. However, this is likely to be less important, as our previous findings have demonstrated similar prediction qualities for assessing frailty using either the dominant or the nondominant arm [15].

Second, several of the screened individuals (35%) that were admitted to the hospital were not able to perform the UEF test, due to severe head injuries or unconsciousness. Although several fall patients were not able to perform the UEF test, this limitation also exists for other common frailty measures such as the Fried (gait-limited) or Rockwood (memory-limited) indices.

Third, all consecutively admitted trauma patients with ground-level falls were screened for the study. As the purpose of the current study was to predict adverse health outcomes in general geriatric trauma patients, the participants were not stratified based on the type of treatment and medication. Also, no information regarding physical therapy or occupation therapy evaluations and treatments during and after hospitalization was available. However, only 1 trauma surgeon (B.J., who was blinded to the frailty and health outcome results) was assigned to all recruited participants.

Fourth, due to time limitations for trauma patient visits, no extensive subjective questionnaires including depression, comorbidity, and cognition were collected in the current study. The purpose of the study was, however, to predict health outcomes using a general UEF test without considering the source of the functional decline (either comorbidity or cognition). Of note, in our previous work we had observed that cognitive impairment caused a reduction in UEF performance [40].

Lastly, our frailty measure was not able to predict hospital length of stay, probably due to other confounding variables that may influence hospitalization, such as diagnosis-related group reimbursement, surgical processes, and rehabilitation requirements. Also 60-day prospective falls were not considered as an outcome, since some data were missing.

Summary of the Findings and Clinical Implications

Health outcomes following traumatic fall events vary widely due to the heterogeneity of health conditions among older adults. Risk adjustment is crucial in order to determine the appropriate treatment, support, and discharge of geriatric trauma patients – identifying those who will benefit from intensive and expensive treatments versus those

who will best respond to palliation – and to better manage appropriate discharge according to disposition. Within the current study, we developed an objective method for assessing frailty based on speed, strength, and exhaustion levels of UEF. Using this approach, an unfavorable discharge disposition to a skilled nursing facility or death, readmission, and prospective falls was identified among older adults with ground-level fall events. Importantly, chronological age was not a significant predictor of unfavorable discharge disposition and readmission. Among the functional parameters used for developing the UEF index, the level of upper-extremity exhaustion was the only parameter that was consistently different between all adverse health outcome measures following hospitalization.

In conclusion, the current results suggest that a simple UEF measure that can be performed at the bedside would allow clinicians to understand the level of frailty, to help identify older adults with a higher risk of discharge complications and readmission.

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Authors' Contributions

B.J. was responsible for the concept and design, clinical supervision, interpretation of data, and obtaining funding; M.R.H. for patient recruitment, study coordination, acquisition of data, and data analysis; N.T. for the concept and design, study coordination, analysis and interpretation of data, preparation of the manuscript, and statistical analysis; T.O.J. for study coordination and acquisition of data; J.M. for the concept and design and interpretation of data; and B.N. for the concept and design, study supervision, interpretation of data, and obtaining funding. All authors contributed by critically revising the manuscript and gave final approval of the version to be published.

Disclosure Statement

The Upper Extremity Frailty meter is protected by a patent pending (US Patent 20,150,332,004). The patent is owned by the University of Arizona, and N.T., J.M., and B.N. are listed as co-inventors on this patent pending. No other conflict of interest is reported by other authors.

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