

Gait Speed as an Incremental Predictor of Mortality and Major Morbidity in Elderly Patients Undergoing Cardiac Surgery

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- Objectives** The purpose of this study was to test the value of gait speed, a clinical marker for frailty, to improve the prediction of mortality and major morbidity in elderly patients undergoing cardiac surgery.
- Background** It is increasingly difficult to predict the elderly patient's risk posed by cardiac surgery because existing risk assessment tools are incomplete.
- Methods** A multicenter prospective cohort of elderly patients undergoing cardiac surgery was assembled at 4 tertiary care hospitals between 2008 and 2009. Patients were eligible if they were 70 years of age or older and were scheduled for coronary artery bypass and/or valve replacement or repair. The primary predictor was slow gait speed, defined as a time taken to walk 5 m of ≥ 6 s. The primary end point was a composite of in-hospital post-operative mortality or major morbidity.
- Results** The cohort consisted of 131 patients with a mean age of 75.8 ± 4.4 years; 34% were female patients. Sixty patients (46%) were classified as slow walkers before cardiac surgery. Slow walkers were more likely to be female (43% vs. 25%, $p = 0.03$) and diabetic (50% vs. 28%, $p = 0.01$). Thirty patients (23%) experienced the primary composite end point of mortality or major morbidity after cardiac surgery. Slow gait speed was an independent predictor of the composite end point after adjusting for the Society of Thoracic Surgeons risk score (odds ratio: 3.05; 95% confidence interval: 1.23 to 7.54).
- Conclusions** Gait speed is a simple and effective test that may identify a subset of vulnerable elderly patients at incrementally higher risk of mortality and major morbidity after cardiac surgery. (J Am Coll Cardiol 2010;56:1668-76)
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Elderly patients account for half of the cardiac surgeries performed in North America and as many as 78% of the major complications and deaths (1). Advanced age, usually defined as age 70 years and older in the context of cardiac surgery, is one of the pre-eminent risk factors for mortality and major morbidity. Nevertheless, randomized (2,3) and observational (4-6) studies have consistently shown that

elderly patients achieve sizable benefits from cardiac surgery. These benefits span the domains of quality of life, allevia-

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tion of symptoms, prevention of major adverse cardiovascular events, and increased survival.

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This high-risk/high-benefit dichotomy renders the clinician's decision-making process particularly challenging. Numerous risk scores have been validated to illuminate this decision making process (7), yet they perform poorly in the elderly, overestimating mortality by as much as 250% (8,9). Furthermore, most risk scores were developed to predict mortality and perform poorly when used to predict major morbidity (10,11). Prediction of morbidity is particularly relevant to the elderly because they have less resiliency to complications and because complications are a major driver of costs, quality of life, and long-term mortality (10,12).

Accurately predicting outcomes in the elderly requires representation of the heterogeneity that exists in this population. This heterogeneity extends beyond differences in comorbid conditions to subclinical impairments in multiple interrelated systems. Accumulation of these subclinical impairments results in reduced homeostatic reserve and resiliency to stressors, a syndrome known as frailty (13). Slow gait speed has been validated as a reliable measure of frailty (14,15) and more recently associated with a heightened risk of cardiovascular death (16). Cardiac surgery is a major physiologic stressor, and because gait speed is a measure of frailty and resiliency to stressors, it is well suited to foreshadow an individual's recovery after cardiac surgery. Thus, the objective of this study was to test the ability of gait speed to predict mortality and major morbidity in a prospective multicenter cohort of elderly patients undergoing cardiac surgery.

Methods

Study design. A prospective cohort of elderly patients undergoing cardiac surgery at 4 university-affiliated tertiary care centers across the U.S. and Canada between February 2008 and June 2009 was assembled. Consecutive patients scheduled to undergo cardiac surgery were screened. Eligible patients were approached and asked to complete a questionnaire and a 5-m (16.4-foot) gait speed test. Based on this 5-m gait speed test, patients were classified as having slow or normal gait speed, which served as the primary predictor variable for this study. The treating physicians and patients were blinded to the gait speed test results so as not to influence their decision to proceed with the surgery or their post-operative management. Follow-up continued until discharge or transfer from hospital, at which time post-operative events were abstracted from medical records. This paper was prepared in accordance with the standards set forth by the STROBE (Strengthening of Reporting of Observational Studies in Epidemiology) Statement (17). Ethics approval was obtained from the institutional review board at each of the participating centers. Patients signed an informed consent to participate.

Participants. Inclusion criteria were: 1) 70 years of age and older; and 2) scheduled to undergo cardiac surgery, defined as coronary artery bypass and/or valve replacement or repair via a standard sternotomy. If patients had their surgeries

cancelled, they were not considered in the analysis. Exclusion criteria were: 1) emergent surgery, defined as a surgery for which there should be no delay due to ongoing refractory cardiac compromise; 2) clinical instability, defined as active coronary ischemia, decompensated heart failure not yet stabilized, or any acute process causing significant symptoms or abnormal vital signs; and 3) severe neuropsychiatric condition causing inability to cooperate with the study procedures.

Predictor variables. The primary predictor variable was 5-m gait speed. A well-lit, unobstructed hallway with markings at 0 and 5 m was used for the test. Patients started at the 0-m line and were instructed to walk at a comfortable pace past the 5-m line. Patients were permitted to use an aid such as a cane or walker. A standard digital stopwatch timed the travel between the first footfall after the 0-m line and the first footfall after the 5-m line (15). This sequence was repeated 3 times, allowing approximately 15 s between trials. The average of the 3 times was calculated. Examiners were trained to measure gait speed at the onset of the study and periodically retrained thereafter.

To identify an optimal cutoff for slow gait speed for mortality or major morbidity prediction in our population, receiver-operator characteristic curves were constructed and a cutoff of ≥ 6 s was chosen to maximize the percentage of patients correctly classified. Thus, the time to walk 5 m of ≥ 6 s was classified as slow gait speed, whereas < 6 s was classified as normal gait speed. Sensitivity analyses were performed using different cutoffs for slow gait speed and using gait speed as a continuous variable. Although speed is typically measured in m/s, it was elected to report it in seconds (taken to walk 5 m) to facilitate subsequent bedside application and interpretation of this test in clinical practice without any calculations.

Outcome variables. The primary end point was in-hospital post-operative mortality or major morbidity, defined by the Society of Thoracic Surgeons (STS) as a composite of all-cause death and 5 major complications. These 5 major complications were stroke (central neurologic deficit persisting > 72 h), renal failure (new requirement for dialysis or increase in serum creatinine $> 153 \mu\text{mol/l}$ [> 2 mg/dl] and > 2 -fold the pre-operative level), prolonged ventilation (> 24 h), deep sternal wound infection (requirement for operative intervention and antibiotic therapy, with positive culture), and need for reoperation (for any reason). Patients were classified in a dichotomous fashion as meeting the end point if they had ≥ 1 of these complications and/or death. To avoid observer bias, the physician ascertaining outcomes from medical records was blinded to the questionnaire and gait speed data. Secondary end points were all-cause death, discharge to a health care facility (rehabilitation, convalescence, other hospital, nursing home) for

Abbreviations and Acronyms

CI = confidence interval

IDI = integrated discrimination index

OR = odds ratio

STS = Society of Thoracic Surgeons

ongoing medical care or rehabilitation, and prolonged post-operative length of hospital stay (>14 days after the index surgery).

Covariates. Although the list of cardiac surgery risk factors is exhaustive, 7 core risk factors account for >75% of the observed variance in mortality (18,19). These core risk factors were age, female sex, previous cardiac surgery, left ventricular ejection fraction <40%, stenosis of the left main coronary artery \geq 50%, nonelective surgery, and type of surgical procedure. Risk scores integrate several risk factors and aim to predict the probability of an adverse outcome after cardiac surgery. Five of the most validated risk scores were calculated: STS predicted mortality or major morbidity (1), STS predicted mortality (1), Additive EuroSCORE (20), Logistic EuroSCORE (21), and Revised Parsonnet Score (22). The STS predicted mortality or major morbidity, herein referred to as the STS risk score, was selected as the main risk score because it was specifically designed to predict this study's primary end point, whereas the others were designed to predict mortality and only subsequently shown to predict morbidity.

Study size. The expected incidence of our primary composite end point was 33% based on a preliminary chart review (Dr. Sandra Dial, unpublished data, April 2007).

The expected proportion of patients with slow gait speed was 50% based on studies of gait speed in elderly cardiovascular patients (14). Assuming a 2-sided alpha of 0.05 and a beta of 0.80, 136 patients were required to show a 2-fold increase in events.

Statistical methods. Multivariable analyses were performed with logistic regression modeling and reported as odds ratios (ORs) with their 95% confidence intervals (CIs). Because the number of risk factors in patients undergoing cardiac surgery is very large, entering all the variables in the model would have resulted in model instability and overfitting. Therefore, a priori, the 7 core risk factors were pre-selected to be entered in the model. Sensitivity analysis with additional risk factors was performed to ensure that significant confounding had not been overlooked. For our primary predictor variable (gait speed), missing values were inferred from our inter-related secondary predictor variable, which was a questionnaire-based frailty score (23). Patients with missing gait speed (n = 12) were inferred to have slow gait speed if their frailty score was positive for at least 3 of the 4 remaining items (n = 2 of 12). The frailty score has previously been shown to be closely correlated with gait speed in cardiovascular patients (area under the curve = 0.89) (14). This approach was thought to be more direct and

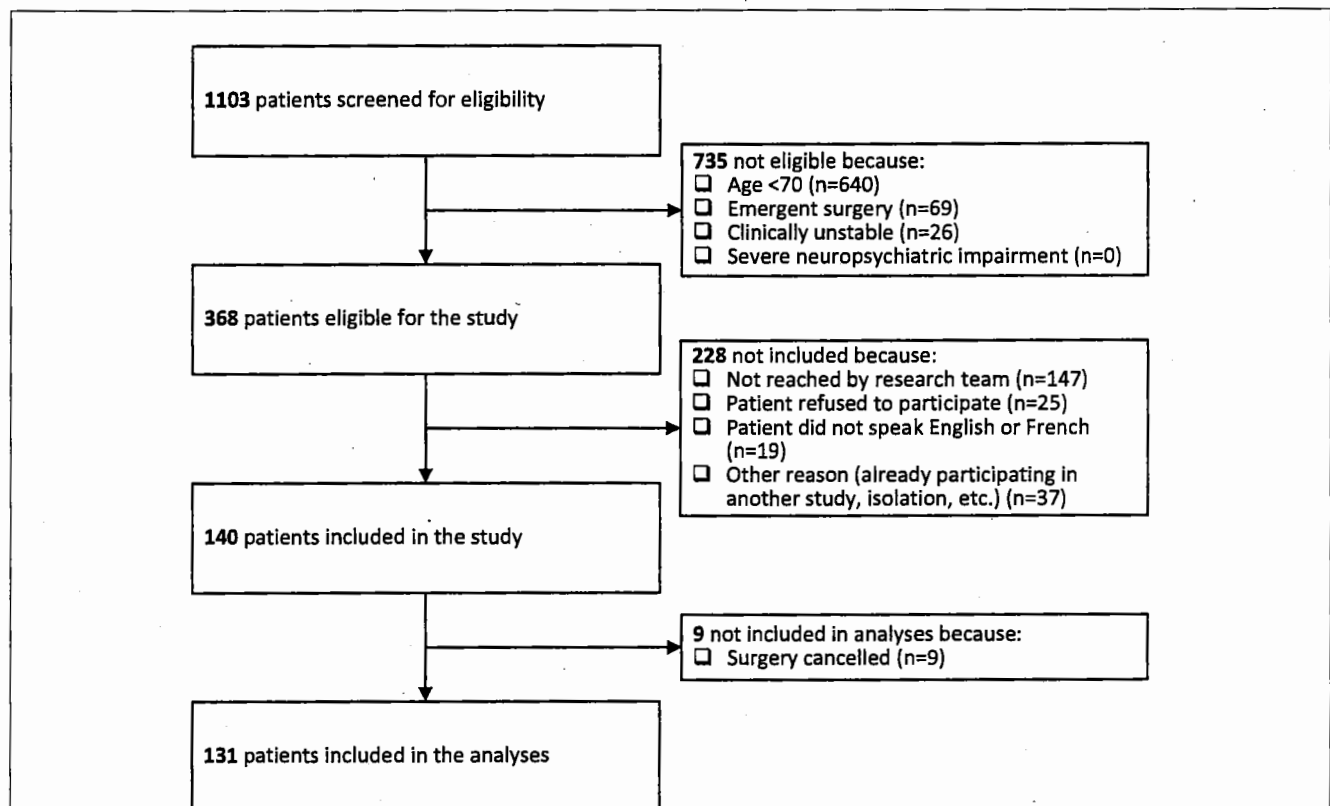


Figure 1 Flow Diagram

The vast majority of patients not reached by the research team were patients who presented during off-hours and were operated on early the next morning. Their baseline and operative characteristics were similar to the patients enrolled in the study.

transparent compared with multiple imputation techniques. Sensitivity analysis excluding patients with missing gait speed was also performed.

The performance of the model was assessed before and after addition of gait speed to determine its incremental value. Specifically, global model fit was measured with the Akaike information criterion and the Bayesian information criterion. Model calibration, which reflects the agreement between predicted and observed risks, was measured with the Hosmer-Lemeshow goodness-of-fit chi-square test and with visual inspection of calibration plots. Model discrimination, which reflects the ability to assign a higher predicted risk to those who will have the observed outcome, was measured with the area under the curve (also known as the

c-statistic) (24). Reclassification was assessed with the integrated discrimination index (IDI) statistic described by Pencina et al. (25). The IDI is the average increase in sensitivity of the model (integrated across all possible values) without incurring a decrease in specificity after adding a new covariate. All analyses were performed with the STATA version 10 statistical software package (StataCorp, College Station, Texas).

Results

The cohort consisted of 131 patients (Fig. 1) with a mean age of 75.8 ± 4.4 years; 23% were octogenarians and 34% were female patients. No patients were lost to follow-up.

Table 1 Baseline Covariates, Stratified by Gait Speed

	Overall	Normal Gait Speed (n = 71, 54%)	Slow Gait Speed, (n = 60, 46%)	p Value
Age, yrs	75.8 ± 4.4	75.4 ± 4.5	76.2 ± 4.2	0.29
Female sex	44 (34)	18 (25)	26 (43)	0.03
Body mass index, kg/m ²	27.1 ± 4.6	26.5 ± 4.0	27.8 ± 5.1	0.09
Comorbid conditions				
Diabetes	50 (38)	20 (28)	30 (50)	0.01
Hypertension	95 (73)	51 (72)	44 (73)	0.85
Dyslipidemia	87 (66)	49 (69)	38 (63)	0.49
Active smoking	12 (9)	6 (8)	6 (10)	0.82
Myocardial infarction	50 (38)	25 (35)	25 (42)	0.45
Chronic heart failure	38 (29)	21 (30)	17 (28)	0.88
LVEF, %	53.6 ± 13.9	54.0 ± 13.4	53.1 ± 14.5	0.73
LVEF <40%	20 (15)	7 (10)	13 (22)	0.06
Left main stenosis ≥50%	38 (29)	25 (35)	13 (22)	0.09
Previous cardiac surgery	8 (6)	3 (4)	5 (8)	0.47
COPD	35 (27)	18 (25)	17 (28)	0.70
Stroke	14 (11)	5 (7)	9 (15)	0.14
Chronic renal failure	21 (16)	9 (13)	12 (20)	0.26
Peripheral arterial disease	13 (10)	8 (11)	5 (8)	0.58
Dementia (MMSE <24)	35 (27)	16 (24)	19 (32)	0.30
Depression (HADS-D >11)	6 (5)	1 (1)	5 (8)	0.10
IADL, disabilities out of 7	0.7 ± 1.3	0.3 ± 0.9	1.2 ± 1.5	0.0002
ADL, disabilities out of 6	0.1 ± 0.6	0.1 ± 0.7	0.03 ± 0.2	0.39
Cardiac surgery risk scores				
STS mortality or major morbidity, %	18.3 ± 9.3	16.3 ± 7.2	20.7 ± 11.0	0.006
STS mortality, %	3.1 ± 2.6	2.6 ± 1.9	3.7 ± 3.2	0.01
Logistic EuroSCORE, %	10.2 ± 9.9	9.0 ± 8.4	11.7 ± 11.3	0.12
Revised Parsonnet score, points	20.8 ± 10.7	18.7 ± 10.1	23.3 ± 10.8	0.01
Type of surgery				
Isolated CABG	78 (60)	42 (59)	36 (60)	
Valve	24 (18)	12 (17)	12 (20)	
Valve + CABG	29 (22)	17 (24)	12 (20)	
Urgent	70 (53)	36 (51)	34 (57)	0.50
Off-pump*	14 (18)	7 (17)	7 (19)	0.75
Frailty markers				
Gait speed (mean time to walk 5 m), s	6.6 ± 2.9	5.0 ± 0.6	8.2 ± 3.3	<0.0001
Frailty score ≥3	24 (18)	2 (8)	22 (92)	<0.0001

Values are mean ± SD or n (%). Missing data: 4 patients did not perform MMSE, HADS, and IADL/ADL, 12 patients did not perform gait speed test; otherwise data complete. *Off-pump not applicable to 53 patients who did not have isolated CABG.

ADL = activities of daily living; CABG = coronary artery bypass graft surgery; COPD = chronic obstructive pulmonary disease; MMSE = Mini-Mental State Examination; HADS = Hospital Anxiety and Depression Scale; IADL = instrumental activities of daily living; LVEF = left ventricular ejection fraction; STS = Society of Thoracic Surgeons.

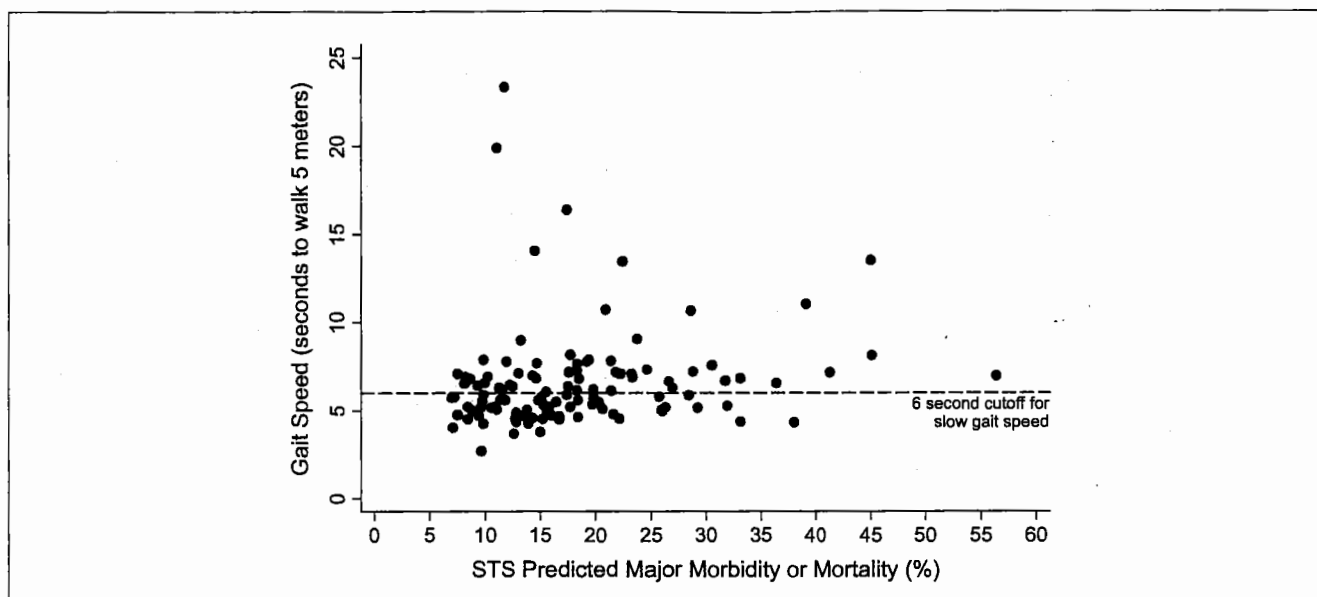


Figure 2 Lack of Correlation Between Gait Speed and the STS Risk Score, Reflecting Distinct Domains

Lack of correlation between gait speed and Society of Thoracic Surgeons (STS) score ($R = 0.14$, $p = 0.13$), showing that gait speed represents a distinct domain. In addition, there was no correlation between gait speed and age or left ventricular ejection fraction.

Baseline characteristics stratified by slow and normal gait speed are shown in Table 1. Sixty patients (46%) were classified as having slow gait speed before cardiac surgery. Patients with slow gait speed were more likely to be female (43% vs. 25%, $p = 0.03$), have shorter height (1.65 m vs. 1.69 m, $p = 0.01$), diabetes (50% vs. 28%, $p = 0.01$), and at least 1 disability in instrumental activities of daily living (48% vs. 18%, $p < 0.0001$). There was no correlation between gait speed and STS risk score, suggesting that these were representing distinct domains (Fig. 2).

Thirty patients (23%) experienced the primary composite end point of mortality or major morbidity after cardiac surgery. Outcome variables and univariate comparisons stratified by slow and normal gait speed are shown in Table 2. A logistic regression model containing the 7 core risk factors and slow gait speed showed that slow gait speed was an independent predictor of mortality

or major morbidity (adjusted OR: 3.17; 95% CI: 1.17 to 8.59) along with previous cardiac surgery (adjusted OR: 7.93; 95% CI: 1.34 to 47.02) and age 80 years and older (adjusted OR: 3.98; 95% CI: 1.43 to 11.12). The performance of the model improved after addition of gait speed (Table 3).

Another logistic regression model containing the STS risk score and slow gait speed similarly showed that slow gait speed was an independent predictor of mortality or major morbidity (adjusted OR: 3.05; 95% CI: 1.23 to 7.54) along with the STS risk score (adjusted OR: 1.05; 95% CI: 1.004 to 1.10) and that the performance of the model improved after addition of gait speed (Table 4). For a given STS predicted risk of mortality or major morbidity, the predicted risk based on our regression model was 2- to 3-fold greater in patients with slow gait speed compared with patients with normal gait speed (Fig. 3). When used in

Table 2 Outcome Variables, Stratified by Gait Speed

	Overall	Normal Gait Speed (n = 71, 54%)	Slow Gait Speed (n = 60, 46%)	p Value
Mortality or major morbidity	30 (23)	9 (13)	21 (35)	0.002
Mortality	7 (5)	1 (1)	6 (10)	0.047
Renal failure	9 (7)	2 (3)	7 (12)	0.079
Stroke	5 (4)	1 (1)	4 (7)	0.18
Deep sternal wound infection	3 (2)	1 (1)	2 (3)	0.59
Prolonged ventilation	13 (10)	4 (6)	9 (15)	0.09
Reoperation	12 (9)	3 (4)	9 (15)	0.06
Prolonged post-operative length of stay (>14 days)	34 (26)	13 (18)	21 (35)	0.03
Discharge to a health care facility*	39 (31)	14 (20)	25 (46)	0.002

Values are n (%). Missing data: data complete for all patients. *Discharge to a health care facility (rehabilitation, convalescence, other hospital, or nursing home) not applicable to 7 patients who died.

Table 3 Incremental Value of Gait Speed Above Core Risk Factors to Predict Mortality or Major Morbidity

	Model Without Gait Speed	Model With Gait Speed
Variables entered in model*		
Age ≥80 yrs	4.22 (1.55-11.47)	3.98 (1.43-11.12)
Female sex	2.25 (0.89-5.71)	1.90 (0.72-5.01)
Previous cardiac surgery	8.1 (1.49-44.09)	7.93 (1.34-47.02)
LVEF <40%	2.17 (0.67-7.05)	1.81 (0.54-6.03)
Left main stenosis ≥50%	0.60 (0.18-1.99)	0.75 (0.22-2.56)
Urgent surgery	1.11 (0.41-3.01)	0.91 (0.33-2.55)
Nonisolated CABG	1.99 (0.70-5.63)	2.15 (0.76-6.07)
Slow gait speed	—	3.17 (1.17-8.59)
Model performance		
AIC	133	129
BIC	-483	-483
Hosmer-Lemeshow chi-square†	6.78 (0.56)	5.70 (0.68)
AUC‡	0.78 (0.69-0.87)	0.81 (0.73-0.89)
IDI‡	4% (0%-7%)	

Improved model performance is suggested by a decrease in AIC, BIC, and Hosmer-Lemeshow chi-square; an increase in AUC; and a positive IDI (24.25). *Expressed as odds ratio (95% CI). †Expressed as value (p value). ‡Expressed as value (95% CI).

AIC = Akaike information criterion; AUC = area under the curve; BIC = Bayesian information criterion; CI = confidence interval; IDI = integrated discrimination index; other abbreviations as in Table 1.

combination, gait speed and the STS risk score effectively stratified patients into distinct risk categories (Fig. 4).

Independent predictors of discharge to a health care facility were slow gait speed (adjusted OR: 3.19; 95% CI: 1.40 to 8.41) and age 80 years and older (adjusted OR: 3.19; 95% CI: 1.19 to 8.60). Independent predictors of prolonged post-operative length of stay were age 80 years and older (adjusted OR: 2.95; 95% CI: 1.15 to 7.59) and a trend for slow gait speed (adjusted OR: 2.32; 95% CI: 0.95 to 5.67). No individual risk factors were predictive of mortality in multivariable analysis; however, 10 deaths (10%) were observed in patients with slow gait speed compared with 1 death (1%) in patients with normal gait speed. Events were evenly distributed across study centers.

No statistically significant interactions were found. Despite this, there was a signal suggesting that the effect of slow gait speed may be modified by female sex. The adjusted OR for mortality or major morbidity was 8.62 (95% CI: 1.46 to 51.00) in female patients and 1.65 (95% CI: 0.50 to 5.43) in male patients, suggesting a trend toward interaction ($p = 0.18$). Therefore, female patients with slow gait speed may be a particularly high-risk subgroup. Patients with slow gait speed undergoing aortic valve replacement also seemed to be at a higher risk of experiencing a major adverse post-operative event. The adjusted OR for mortality or major morbidity was increased to 4.13 (95% CI: 1.06 to 16.13) in the subgroup of 46 patients who underwent aortic valve replacement, either in isolation or in combination with coronary artery bypass graft.

In sensitivity analyses, the variables found to be associated with gait speed and mortality or major morbidity in univariate analyses were added to the 7 core risk factor model. The

expanded model did not reveal residual confounding. Patients with missing gait speed data were excluded, and this did not change the results. The impact of gait speed was similarly significant regardless of the risk score used (STS, Additive or Logistic EuroSCORE, Revised Parsonnet) and the gait speed cutoff (≥ 5 , ≥ 6 , ≥ 7 , ≥ 7.7 s or continuous variable). The dichotomous cutoff of ≥ 6 s to walk 5 m was consistently more robust, achieving superior discrimination to predict the end points of interest.

Discussion

The principal finding of this study is that 5-m gait speed is an incremental predictor of mortality and major morbidity in elderly patients undergoing cardiac surgery, associated with a 2- to 3-fold increase in risk. This simple, rapid, and inexpensive test effectively stratifies patients beyond traditional estimates of risk, which tend to be inaccurate in the elderly. Addition of gait speed to existing cardiac surgery risk models resulted in improved model performance, translating into more accurate prediction of who will experience a major adverse post-operative event and who will need to be discharged to a health care facility for ongoing medical care or rehabilitation.

There are no previous studies specifically focusing on the use of gait speed as a predictor of post-operative mortality and morbidity in elderly cardiac surgery patients. Two studies incorporated disabilities in activities of daily living as a predictor of outcomes after cardiac surgery (26,27). Although there is no universally accepted definition for frailty, it is generally agreed that disability and frailty are different entities (28). One study evaluated frailty as a predictor of outcomes after elective noncardiac surgery (29). Consistent with our findings, those who were frail had higher rates of complications, higher rates of discharge to a health care facility, and longer lengths of hospital stay.

This study's analytic approach sought to demonstrate the incremental prognostic value of slow gait speed rather than

Table 4 Incremental Value of Gait Speed Above the STS Risk Score to Predict Mortality or Major Morbidity

	Model Without Gait Speed	Model With Gait Speed
Variables Entered in Model		
Variables entered in model*		
STS risk score	1.06 (1.02-1.11)	1.05 (1.004-1.10)
Slow gait speed	—	3.05 (1.23-7.54)
Model performance		
AIC	137	133
BIC	-496	-497
Hosmer-Lemeshow chi-square†	11.53 (0.17)	10.29 (0.25)
AUC‡	0.70 (0.60-0.80)	0.74 (0.64-0.84)
IDI‡	5% (1%-8%)	

Improved model performance is suggested by a decrease in AIC, BIC, Hosmer-Lemeshow chi-square; an increase in AUC; and a positive IDI (24.25). STS risk score indicates the predicted risk of mortality or major morbidity according to the STS risk score (percentage). *Expressed as odds ratio (95% CI). †Expressed as value (p value). ‡Expressed as value (95% CI).

Abbreviations as in Tables 1 and 3.

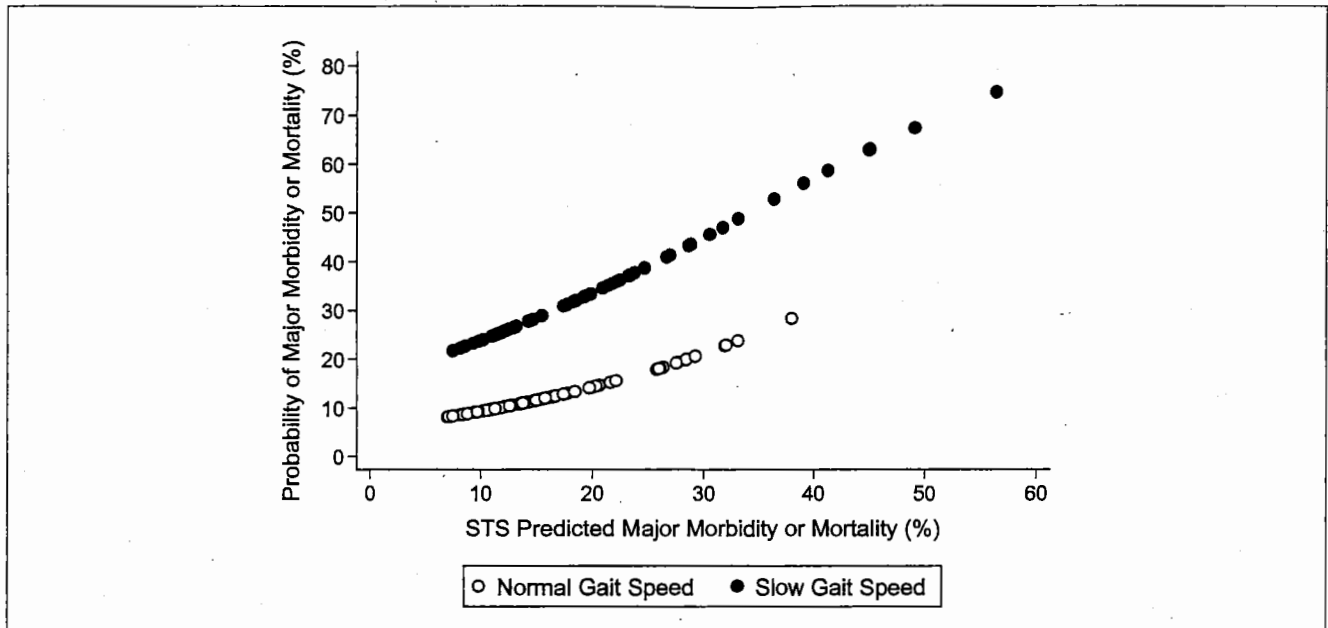


Figure 3 Predicted Probability of Mortality or Major Morbidity According to Gait Speed and the STS Risk Score
Slow gait speed (solid circles) conferred a 2- to 3-fold increase in risk for any given level of Society of Thoracic Surgeons (STS) predicted mortality or major morbidity compared with normal gait speed (open circles). The adjusted odds ratio for mortality or major morbidity was 3.05 (95% confidence interval: 1.23 to 7.54).

simply showing that it was a significant predictor. The statistical significance of a new marker does not imply clinical significance or improvement in model performance. Pencina et al. (24) and Cook and Ridker (30) have emphasized the importance of evaluating model performance before and after the addition of a new marker. Novel reclassification statistics such as the IDI have been developed and are being increasingly used in epidemiological studies because they provide a more sensitive and intuitive

estimate of change in model performance. The IDI was found to be the most sensitive indicator of improvement in model performance after adding gait speed to traditional risk factors (IDI: 5%; 95% CI: 1% to 8%). Moreover, the IDI was more intuitive than other statistical tests; whereas the change in the area under the curve from 0.78 to 0.81 is difficult to gauge, the IDI of 5% is essentially the average increase in sensitivity after incorporating gait speed assuming no decrease in specificity.

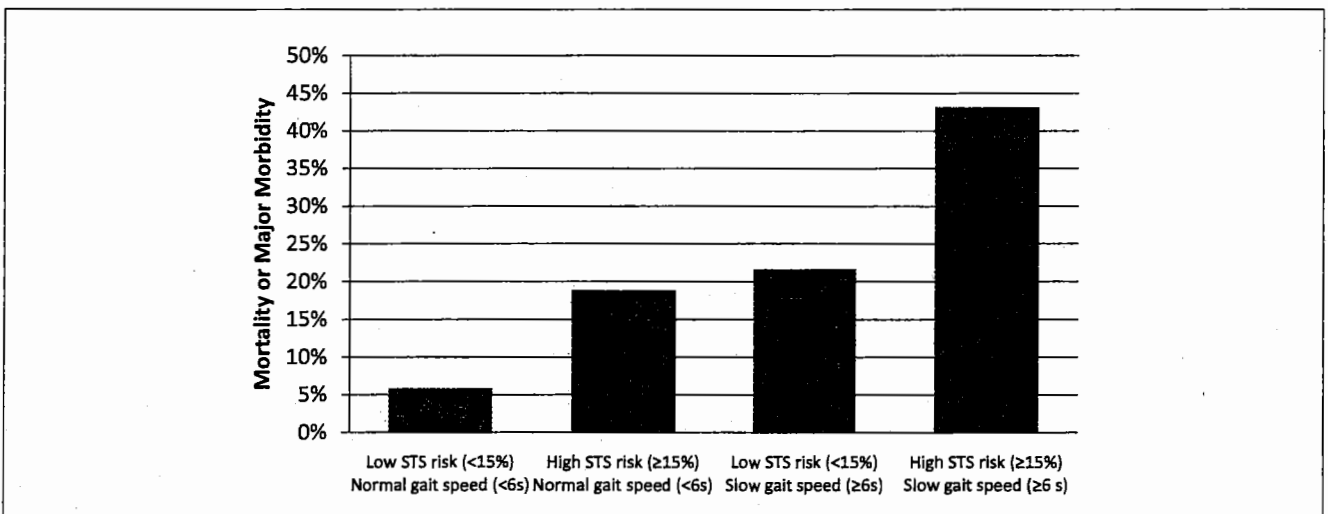


Figure 4 Mortality or Major Morbidity According to Gait Speed and the STS Risk Score
The dual risk factors of slow gait speed (≥ 6 s to walk 5 m) and high Society of Thoracic Surgeons (STS) score ($\geq 15\%$ predicted mortality or major morbidity) identified patients at the highest risk. Among those with the dual risk factors, 43.2% experienced a major morbidity or mortality compared with only 5.9% of those without either risk factor.

The clinical impact of measuring gait speed before cardiac surgery is 3-fold. First, by refining risk predictions in this challenging group, clinicians can have a more comprehensive assessment of their patient and provide a more accurate estimate of risk to the patient. Risk predictions should not be used to determine operability, because no level of predicted risk is unequivocally associated with adverse outcomes (31). Second, with the development of minimally invasive techniques such as transcatheter valve implantation, clinicians can better assess who should be offered these therapies. Patients undergoing surgical aortic valve replacement who were identified as being frail (slow gait speed) seemed to be at particularly high risk of adverse outcomes; accordingly, the utility of frailty as a parameter to help steer therapy toward surgical or transcatheter aortic valve replacement is promising and deserves further study. Third, frail patients with slow gait speed may benefit from interventions in the pre-, peri-, or post-operative period. These interventions may include comprehensive geriatric assessment and management (32), intensive monitoring, early mobilization (33), planned discharge to a specialized physical rehabilitation facility, and low-intensity exercise training (34). Targeted therapies are under investigation.

Study limitations. There are a number of limitations in this study. The primary end point was measured in-hospital as opposed to long term, and events occurring after discharge or transfer were not captured. This is particularly relevant for deep sternal wound infections that typically occur weeks after surgery, once patients have been discharged. The STS and other committees have debated this issue and continue to recommend using in-hospital measures (1,18). Only 15 (11%) of our patients were transferred to other hospitals; when patients were transferred, medical records were requested from the second hospital. Systematic differences between nonenrolled and enrolled patients may have introduced bias. Basic data on nonenrolled patients were compared and did not show significant differences. Furthermore, the main reason for nonenrollment was logistical in nature and did not, to the best of our knowledge, reflect patient-related factors. Classic teaching suggests that no more than 1 covariate per 10 events be entered, although more recent simulations have liberalized this rule, especially when performing sensitivity analyses to rule out additional confounding (35). We performed such sensitivity analyses with expanded models. We did not validate our proposed cutoff of 6 s (0.83 m/s) for slow gait speed in an independent dataset, although it is consistent with the range of previously reported cutoffs (0.65 to 1.00 m/s). Last, the number of patients in this study was modest and the 95% CIs surrounding the effect estimates were wide. Definitive recommendations for interpretation and widespread implementation of gait speed testing should be tempered by these limitations.

Conclusions

This study adds to the growing body of literature that has shown that slow gait speed is prevalent in patients with

cardiovascular disease and predictive of adverse outcomes (36). Previously, Purser et al. (14) showed that slow gait speed was the strongest predictor of mortality at 6 months among 399 elderly patients admitted to a cardiology service with severe coronary artery disease (OR: 3.8; 95% CI: 1.1 to 13.1). Cesari et al. (37) showed that gait speed was correlated with inflammatory markers such as C-reactive protein, interleukin-6, and tissue necrosis factor- α , known to play a key role in the pathophysiology and prognosis of cardiovascular disease.

To our knowledge, this is the first study to test the value of gait speed in patients undergoing cardiac surgery. The results of this study may be generalizable to other centers given the multicenter design and the nonrestrictive inclusion criteria intended to reflect real-world practice. Gait speed has the advantage of being applicable in daily practice with minimal investment. Beyond its role as a predictor of outcomes, gait speed demonstrated an incremental value to improve the performance of existing risk models and help overcome some of their relative shortcomings when applied to the elderly patient population. Future efforts should be directed toward validating the optimal cutoff for slow gait speed, implementing gait speed in existing risk models, and developing targeted interventions for vulnerable elderly patients with slow gait speed.

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Key Words: aging ■ bypass ■ epidemiology ■ frailty ■ surgery.

EDITORIAL COMMENT

Frailty, Aging, and Cardiac Surgery Outcomes

The Stopwatch Tells the Story*

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In this issue of the *Journal*, Afilalo et al. (1) suggest a novel screening technique to aid in risk assessment of elderly patients who are to undergo cardiac surgery. Their new screening tool, consisting of an observer, a stopwatch, and a well-lit hallway, is reproducible, and I believe will be extraordinarily cost-effective. Indeed, this study's findings add several new important insights into selection of elderly patients for cardiac surgery. Most importantly, it replaces such subjective tests such as the "eyeball test," which only substantiated that the judgment of clinicians varied greatly in selecting elderly patients for cardiac operations.

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Several observations regarding risk stratification and cardiac surgery highlight the importance of the present study. The explosive growth of the population 65 years of age and older in the U.S. and the high prevalence of cardiovascular disease in this age group will place unprecedented demands on our health care delivery system and its providers. Stated differently, we must prepare ourselves to face decisions regarding treatment options for this exponentially growing segment of our population with scant data to appropriately guide our decisions. Whereas increasing age is a robust statistical predictor of adverse outcomes after cardiac surgical procedures (Society of Thoracic Surgeons risk model), the recognition that physiological age and chronological age differ in many patients. Therefore, age, per se, often does not provide an accurate reflection of risk/benefit in selecting patients for cardiac surgery.

Afilalo et al. (1) explore the boundaries of frailty and cardiac surgery. They offer 3 very important observations in patients older than 70 years of age undergoing elective or

urgent cardiac surgery. 1) They found that patients with slow gait speed, defined as >6 s to walk 5 m, experienced a nearly 3-fold increase in risk after cardiac surgery. 2) Importantly, their observations also showed that the addition of gait speed to existing cardiac surgery risk models vastly improved the predictive value of mortality and morbidity from these models. In this regard, the authors are to be commended for expanding the outcomes beyond mortality in this report because many elderly individuals fear loss of independence as a fate worse than death. As such, the present study showed that a slow gait speed doubled the chances that one would be discharged to a health care facility or would have a prolonged hospital stay. These data are sorely needed when facing elderly patients and counseling them regarding treatment options and expected outcomes. 3) Of particular importance, the interaction of female sex and slow gait speed emerged as a particularly high-risk subgroup. Elderly women with slow gait speed had an 8-fold increase in morbidity or mortality; clearly this group deserves further study to explore the well-described adverse interaction of female sex and cardiac surgery.

Placing this study in perspective is unique because the current literature regarding frailty and cardiac surgery outcomes is sparse. The domains of frailty and disability are separate, and although frailty does not have a universally accepted definition, most would accept slow gait speed as a clinically useful and reproducible measure of frailty. To date, most reports of elderly patients undergoing cardiac surgery are limited to single-center case series, which merely substantiate "proof of concept" that such operations can be performed in selected elderly patients. The one large multicenter, retrospective database series of octogenarians and nonagenarians undergoing cardiac operations reported mortality. This study did not provide any discrimination of who was at profoundly increased risk, other than noting that the traditional risk factors of emergent operations and low ejection fraction pre-operatively predict poor outcomes. These risk factors apply to both young and elderly patients (2). One important caveat regarding the present study is that the mean age of patients was 75 years. It remains unknown whether gait speed would predict outcomes in patients older than 85 or 90 years of age who are to undergo cardiac surgery, and further study of the "oldest old" is necessary. Last, it would be inappropriate to conclude that a person is not a candidate for operation based solely on the 5-m gait speed.

What is certain in the uncertain landscape of health care delivery is that cardiovascular professionals will be faced with an increasing number of older patients who could benefit from cardiac surgery and will ask for a chance to regain functional independence and quality of life. Careful and appropriate patient selection and a technically sound operation will add both quantity and quality to the life of patients older than 75 years of age who have cardiovascular

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disease. Afilalo et al. (1) have given clinicians an important tool to help us care for this exponentially expanding pool of elderly patients with cardiovascular disease.

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