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Timed Stair Climbing is the Single Strongest Predictor of Perioperative Complications in Patients Undergoing Abdominal Surgery

Sushanth Reddy, MD, FACS, Carlo M Contreras, MD, FACS, Brandon Singletary, MPH, T Miller Bradford, Mary G Waldrop, Andrew H Mims, W Andrew Smedley, Jacob A Swords, Wang Thomas N, MD, PhD, FACS, and Heslin Martin J, MD, MSHA, FACS

Abstract

Background—Current methods to predict patients' peri-operative morbidity utilize complex algorithms with multiple clinical variables focusing primarily on organ-specific compromise. The aim of the present study is to determine the value of a timed stair climb (SC) in predicting peri-operative complications for patients undergoing abdominal surgery.

Study Design—From March 2014 to July 2015, 362 patients attempted SC while being timed prior to undergoing elective abdominal surgery. Vital signs were measured before and after SC. Ninety day post-operative complications were assessed by the Accordion Severity Grading System. The prognostic value of SC was compared to the ACS NSQIP risk calculator.

Results—A total of 264 (97.4%) patients were able to complete SC. SC time directly correlated to changes in both mean arterial pressure and heart rate as an indicator of stress. An Accordion grade 2 or higher complication occurred in 84 (25%) patients. There were 8 mortalities (2.4%). Patients with slower SC times had an increased complication rate ($P < 0.0001$). In multivariable analysis SC time was the single strongest predictor of complications ($OR = 1.029$, $P < 0.0001$), and no other clinical co-morbidity reached statistical significance. Receiver operative characteristic curves predicting post-operative morbidity by SC time was superior to that of the ACS risk calculator (AUC 0.81 vs. 0.62, $P < 0.0001$). Additionally slower patients had a greater deviation from predicted length of hospital stay ($P = 0.034$)

Conclusions—SC provides measurable stress, accurately predicts post-operative complications, and is easy to administer in patients undergoing abdominal surgery. Larger patient populations with a diverse group of operations will be needed to further validate the use of SC in risk prediction models.

Corresponding address: Sushanth Reddy, MD, FACS, Department of Surgery, Division of Surgical Oncology, University of Alabama at Birmingham, 1136 Faculty Office Tower, 510 20th Street South, Birmingham, Alabama, 35294, sreddy@uabmc.edu.
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Introduction

The decision of whether to operate on a patient rests with the surgeon being able to discern the relative risk-benefit ratio for both the operative intervention as well any non-operative alternatives. As the adult general population is both aging [1] and developing greater frequency and severity of co-morbidities [2,3], the ability to predict surgical outcomes becomes increasingly important. In the absence of a reliable tool to assess complications the onus falls to the surgeon to judge whether a patient is at high risk of adverse post-operative outcomes.

Current methods to predict outcome focus mainly on the concept of frailty [4,5]. Frailty has mainly been applied to older adults. Though the relationship between physical debilitation and physiologic age has long been appreciated [6,7] a chronological and physiological age are sometimes divergent. Consequently a measure of frailty should be utilized with all patients, not just the elderly. Although generally accepted as a predictor of surgical risk, the definition of frailty varies widely [4,5,8]. Many such calculators utilize both subjective and difficult to determine objective measures in order to calculate frailty. The ASC NSQIP Surgical Risk Calculator is also commonly used to assess risk [9]. This calculator uses a complex algorithm focusing mainly on organ compromise rather than functional status. As a result, neither approach is a practical method for the surgeon in predicting surgical outcomes.

Others have advocated a measure of physiological compromise in the form of the timed up-and-go [10]. Although useful in predicting outcomes timed up-and-go is best utilized in combination with other models. In this study we introduce the concept of inducing a moderately stressful physical activity of climbing a flight of stairs as a method of predicting surgical outcomes. The purpose of this analysis is to determine the physiological stress provided by stair climbing, the ability of stair climbing to forecast operative outcomes, and the use of stair climbing to predict hospital length of stay.

Methods

A prospective cohort study was conducted of patients undergoing planned elective abdominal operative surgery at a single institution from March 5, 2014 to July 22, 2015. Inclusion criteria were the use of general anesthesia, age 19 years or older, and entry into the peritoneal cavity. Patients were included in the study only after they were deemed an appropriate operative candidate by their surgeon. The study was approved by the Institutional Review Board and informed consent was obtained from all participants.

All subjects were asked to walk down and then up one single flight of stairs (7 steps each way) while being timed. Vital signs were collected prior to beginning and immediately after completing the task. Surgeons were blinded to the results of the subjects' performance. Clinical variables were collected prospectively. The presence of hypertension, diabetes mellitus, coronary artery disease, congestive heart failure, tobacco use, hypercholesterolemia, and alcohol abuse were defined as described previously [9]. These variables are all included in the ACS NSQIP Surgical Risk Calculator. Low serum albumin

has been shown to be associated with poor surgical outcomes [11-13]. A cut off of albumin < 3.4 was used as this considered abnormal in our hospital laboratory and was thus used in this analysis. Ninety-day complications were graded using the Accordion Severity Grading System [14]. Grade 2 or higher complications were included in the analysis. Patients who cancelled surgery, underwent a non-abdominal operation, or underwent an emergent operation were excluded from the complication analysis but their data was included in assessing vital signs after stair climbing.

Outcomes were compared to the ACS NSQIP Surgical Risk Calculator [9]. Length of stay was calculated from the date of surgery to the date of discharge, inclusive of both dates. Univariable differences in population characteristics by post-operative complication status were assessed using t-test and two-sided Fisher's exact test statistics. Differences across stair climbing performance time groups for patient vital signs, post-operative complications, and increased length of stay were assessed using Wilcoxon Rank-Sums analyses. Univariable and multivariable logistic regression models were created to assess for significant predictors of complications. To test the ability of the stair climbing task to predict surgical outcomes, we constructed receiver operator characteristic (ROC) curves. All statistical analyses were performed using STATA SE 13.0 (Stata Corp, College Station, TX) and GraphPad Prism 5 (GraphPad Software Inc, La Jolla, CA). The statistical threshold for significance was set at alpha 0.05 for all tests.

Results

Stair Walking and Stress

A total of 362 patients were enrolled in the study. Twenty of these patients were later excluded from complication analysis: 12 patients elected to cancel surgery, 7 underwent operations where the peritoneum was not entered, and 1 underwent an emergent operation prior to his planned elective procedure. Twenty four patients were unable to perform the task (including 20 patients who were included in the complication analysis and 4 who were excluded). For the 338 patients who were able to complete the task, the mean time was 18.0 seconds with a median time 16 seconds (range, 6-108 seconds). Changes in both heart rate and mean arterial pressure were calculated from baseline. Patients who required more time to complete the task had a greater deviation in their vital signs (Figure 1) indicating greater stress from stair climbing. The breakdown of operative intervention is shown in Table 1.

Surgical Complications

A Grade 2 or greater complication occurred in 84 patients (24.6%) and there were 8 mortalities (2.4%). Table 2 compares the common clinical features between patients who experienced a complication and those who did not. These are the variables that have been commonly implicated in frailty and complications. The two groups are similar except the patients who had a complication were older ($P=0.0007$) and slower climbing the stairs ($P<0.0001$). The complication rate increased as the time to climb the stairs increased as well ($P<0.0001$). This is shown in Figure 2.

In univariable analysis (Table 3), stair climbing time and age were both highly statistically significant in predicting complications. A low serum albumin, presence of COPD and hypertension were all close to significance. All five variables were then placed into a multivariable model (Table 4). Only stair climbing time was a predictor of complications in this model, and it remained very significant ($P<0.0001$).

ROC curves were performed for both stair climbing times and the predicted risk of all complications using the ACS NSQIP calculator, which are demonstrated in Figure 3. The area under the curve (AUC) is compared to the null hypothesis. Both models are effective in predicting complications. The AUC for the stair climbing model is 0.8066 ($P<0.0001$) and is 0.6185 ($P=0.0006$) for the ACS NSQIP calculator. The stair climbing model is superior to the ACS NSQIP calculator in predicting complications ($\chi^2 = 26.99$, $P<0.0001$). Stair Climbing Predicting Increased Length of Stay

Because of the relative heterogeneity of the types of procedures the patients underwent in this series, we also tested the ability of the stair climbing time to predict the length of hospital stay. The predicted length of stay was determined using the ACS NSQIP calculator for each patient. The deviation from the length of stay was then calculated as the difference between the actual and predicted length of stay. These data are depicted in Figure 4. The correlative trend between stair climbing time and outcome continues in this analysis: patients who were slower climbing stairs had a greater chance of having an extended hospital length of stay ($P=0.033$).

Colorectal Surgery Patients

We also performed a subgroup analysis of patients who underwent a colorectal operation. Complication rate increased as the stair climbing time increased (Figure 5, $P<0.0001$). Additionally the difference in length of stay increased for patients who were slower to climb stairs though this did not reach statistical significance (Figure 6, $P=0.36$). The lack of statistical significance is likely due to the smaller numbers in this limited cohort. Finally ROC curves (Figure 7) demonstrate that stair climbing is still superior to the ACS NSQIP calculator for predicting complications ($\chi^2=7.43$, $P=0.006$). The AUC for the stair climbing model is 0.7946 ($P=0.002$) and that for the ACS NSQIP calculator is 0.5105 ($P=0.31$).

Discussion

This study demonstrated the utility of a timed stair climb in the pre-operative assessment of a patient undergoing an abdominal surgery. Patients who were slower climbing stairs had greater perturbations in their vital signs from rest. Additionally these patients were at the highest risk of surgical complications. The timed stair climbing model was a stronger predictor of postoperative outcome than the ACS NSQIP model. Finally, deviation from anticipated hospital length of stay was predicted by stair climbing time.

For years the concept that declining physiologic status portends poor operative outcomes has been subjectively recognized. The ability to quantify this notion has just recently been introduced. The current approach, however, has been largely a series of complex calculations using discrete variables in order to summarize the human body's ability to

tolerate surgery. Although these methods have been effective they are also cumbersome to use on a day-to-day basis. The most common of these calculators is the ACS NSQIP Surgical Risk Calculator. This model was derived from the surgical outcomes of 393 NSQIP hospitals across the United States for over 1.4 million patients over a 3.5 year time period. The authors created a universal model that was comparable to most organ specific risk assessment models available. This calculator utilizes 21 pre-operative risk factors (including specific CPT code for the procedure) to estimate 8 different adverse post-operative outcomes [9]. The primary criticism of this calculator is its use of categorical variables to estimate the associated risks of each co-morbidity. For example, patients are categorized as having hypertension or not. There is no discrimination between patients based on the degree of blood pressure control. This is an inherent issue with a tool developed from a large dataset such NSQIP.

Different authors have thus sought to create simpler tools to assess surgical risk. The timed up-and-go (TUG) test to measure walking speed introduced a method to correlate physical debilitation to physiology. TUG is measured as the time it takes a subject to stand from a sitting position, walk 10 feet, return to the chair, and sit. Robinson, et al used the TUG time to predict outcomes of veterans older than 65 undergoing elective colo-rectal or cardiac surgery. Subjects were divided into three groups based on TUG speed. Slower TUG speed did correlate to worse surgical outcomes. TUG speed was superior to the ACS NSQIP Surgical Risk Calculator as well. Interestingly TUG speed also seemed to be a marker of overall physical health as those with slower speeds also had greater comorbidities such as greater ASA score, advanced age, lower albumin and impaired cognition. TUG speed also predicted outcomes at 1 year follow up from surgery [10]. Our criticism of this test however is that the timed up-and-go does not adequately stress the subject. Vital sign measurements were not recorded alongside TUG speed. In this study we have proposed that a timed stair climb is able to provide measurable stress. Indeed patients who were slowest climbing stairs had a increase of 16.6% and 21.8% in their heart rate and mean arterial pressure, respectively (compared to 7.4% and 7.9%, respectively, in the fast climbing group). This indicates that these slow patients are summoning a greater amount of their physiological reserve in order to complete the task. Various authors have found that extended stair climbing is associated with increased physiological stress. These publications focus on thoracic procedures and are far more strenuous. In these studies, patients are asked to climb anywhere from 6 to 11 flights of stairs until they reach exhaustion while timed [15-17]. A greater physiologic stress is provided with more effort but this is likely not feasible for a busy general surgeon and introduces questions of patient safety. To date ours is the first study to examine the role of a focused stair climbing exercise in operative outcomes.

Another popular method to predict outcomes is sarcopenia measurements. Unlike frailty, sarcopenia has a fairly uniform definition and measurements can be reliably reproduced. Total psoas muscle area is measured on CT scan at the L3 vertebral body and compared to visceral fat content at the same axial level. Sarcopenia has been strongly correlated to postoperative complications for a variety of complex abdominal operations [18-21]. Decreased total psoas muscle area correlated to both immediate post-operative complications and recurrence-free survival after liver resection for colorectal metastases [18]. Sarcopenia also correlated to poor long-term survival following resection for

pancreatic adenocarcinoma [19]. Sarcopenia appears to be a surrogate for axial strength. Measuring sarcopenia is a cumbersome task and requires advanced radiology software. Given the limited accuracy of hypoalbuminemia in our study, measuring functional status is likely a surrogate for sarcopenia. Stair climbing is far easier to assess and at a fraction of the cost. Future studies will be needed to correlate axial muscle/fat measurements with stair climbing time to test this hypothesis.

Ultimately these calculators are being developed in order to estimate frailty prior to surgery. The definition of frailty is not consistent. Makary et al did show that frailty was a strong predictor of surgical outcomes. In this study, frailty was calculated using objective (walking speed, grip strength) and subjective (exhaustion, activity level) variables. The authors found that when combined with other risk indices (the American Society of Anesthesia, Lee, and Eagle scores) frailty was predictive of outcome. The authors did not comment on the ability of frailty alone in comparison to these other indices [4]. The ASC NSQIP Surgical Risk Calculator was not available at that time for comparison. Another study defined frailty as a combination of TUG time with other measurable traits (Katz score [22], the Mini-Cog [23], and the Charlson Index [24]. Again, the degree of frailty was predictive of surgical complications following both cardiac and colorectal operations[5]. The authors however did not compare the frailty score with another calculator. The authors openly recognize that the TUG alone does not fully capture frailty[10]. Again, in both of these frailty models, complex calculations are needed to measure surgical risk. Additionally each introduces some degree of subjectivity in defining and measuring frailty. In our current study we suggest that stair climbing speed is in itself a marker for frailty. This may be due to the fact that the stair climb requires a greater stress than was ascribed with the TUG. This will need to be further investigated by comparing stair climbing time to a frailty calculator.

The limitations of this study are two-fold. First we are comparing the stair climbing time to the ACS NSQIP calculator. This calculator was designed to predict 30-day morbidity and mortality. In this study we have assessed the risk of 90-day complications. With this extended window for complication analysis we have inherently stretched the ACS NSQIP calculator's accuracy. However an increasing body of work has established that surgical risk should be assessed beyond the traditional 30-day window. For example, for patients undergoing pancreatectomy, only 70% of major complications are identified using a 30-day window; however, 89% of these complications are captured when extended to a 90-day post-operative period [25]. Sixty-six (79%) patients in our series had a complication within 30-days. We thus feel that the 90-day window is more appropriate for assessing surgical complications. As the ACS NSQIP calculator is the most widely used predictor of operative outcomes this is a reasonable basis of comparison in this study. Second, the patient population in our study has undergone a wide variety of operations. There is an inherent heterogeneity of predicted outcomes based on the surgical complexity. The ACS NSQIP calculator corrects for this by using the specifics of the surgery through the CPT code. We therefore performed a subgroup analysis of colorectal surgery patients, the largest group of patients in this series. Again when compared to the ACS NSQIP calculator the stair climbing model was superior. Thus we feel justified in comparing the stair climbing time to the ACS NSQIP calculator. Additionally we analyzed the change in predicted length of stay and found that, although patients with complex surgeries do stay in the hospital longer, the stair

climbing time correctly predicted which patients would deviate from post-operative clinical pathways.

It would seem that improving high-risk patients' functional status prior to surgery would then correlate to reducing operative morbidity. This concept of "prehabilitation" has been widely discussed, but mixed results have been reported. A prospective trial examining how patients who underwent a prehabilitation regimen prior to colorectal surgery did show that patients who had the largest gains in prehabilitation were more likely to return to their baseline functional scores but did not note any difference in complications [26]. Similarly patients undergoing prehabilitation had no difference in surgical outcomes compared to those undergoing post-operative rehabilitation [27,28]. A single study has shown that prehabilitation improves hospital lengths of stay without effecting complications for colorectal surgery patients [29].

Conclusion

In summary, a timed stair climb is an effective method to assess pre-operative physiological reserve. This reliably induces stress on the patient that can be measured. It is also the single strongest predictor of operative outcomes in patients undergoing abdominal surgery. Finally it can be easily performed in comparison to the plethora of complex models described elsewhere. Use of the timed stair climb can be helpful in the decision making algorithm for patients undergoing elective abdominal surgery.

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Figure 1.

Stair Climbing and Changes in Vital Signs (VS). Changes in patients' heart rate (HR) and mean arterial pressure (MAP) were calculated as a function of the stair climbing time. Patients who were slower climbing stairs had a greater deviation in their vital signs (Wilcoxon Rank Sum Test, $p < 0.0001$).

Figure 2. Stair Climbing Time and Surgical Complications. Patients who were slower to climb stairs had an increased complication rate (Wilcoxon Rank Sum Test, $p < 0.0001$).

Figure 3.

Receiver Operator Characteristic (ROC) Curves. The area under the curve is compared to the null hypothesis (diagonal line) where the area is 0.5. The stair climbing time is in blue and the ACS NSQIP curve is in red. For the stair climbing time and the ACS NSQIP calculator the area under the curve is 0.8066 (95% confidence interval 0.75508-0.85806) and 0.6185 (95% confidence interval 0.54840-0.68863), respectively. The difference in the curves is statistically significant ($p < 0.0001$).

Figure 4.

Stair Climbing and Hospital Length of Stay. The deviation from predicted length of stay was calculated by subtracting the predicted length of stay from the actual length of stay. Patients who were slower climbing stairs had a relative increase length of stay (Wilcoxon Rank Sum Test, $p=0.033$).

Figure 5. Stair climbing time and complications for colorectal surgery patients. Slower patients had an increased complication rate (Wilcoxon Rank Sum Test, $p < 0.0001$).

Figure 6. Stair Climbing and Length of Stay for Colorectal Surgery Patients. A stepwise trend is observed as patients with increased stair climbing time had a greater deviation from their expected length of stay but this did not reach statistical significance ($p=0.36$).

Figure 7.

Receiver Operator Characteristic (ROC) Curves for Colorectal Surgery Patients. The stair climbing time is in blue and the ACS NSQIP curve is in red. For the stair climbing time and the ACS calculator the area under the curve is 0.7946 (95% confidence interval 0.64693-0.94236) and 0.5105 (95% confidence interval 0.32074-0.70027), respectively. The difference in the curves is statistically significant ($p=0.006$).

Table 1

Operative Breakdown of the 342 Patients Who Underwent Surgery in the Study.

Operation	n (%)
Colorectal	88 (26)
Pancreatic	58 (17)
Gastro-esophageal	41 (12)
Liver	38 (11)
Small bowel	34 (10)
Retroperitoneal	30 (9)
Other	53 (15)

Table 2

Comparison of Patients with Complications.

Variable	Complication (n=84)	No Complication (n=258)	p Value
Age, y, median	65	59	0.0007
Sex, female, %	60	50	0.13
Race, caucasian	72	75	0.57
Tobacco use, %	17	22	0.35
Hypertension, %	65	56	0.16
Diabetes, %	34	23	0.88
Coronary artery disease, %	10	11	0.84
Congestive heart failure, %	2	4	1.0
COPD, %	10	5	0.12
Hypercholesterolemia, %	34	29	0.41
Alcohol abuse, %	4	6	0.43
BMI, median	28.5	28.1	0.77
Stair climbing time, seconds	22.9	15.0	<0.0001
Albumin < 3.4 g/dL, %	19	11	0.08

Continuous variables were assessed with a t-test and categorical variables were assessed with a two-sided Fisher's exact test.

Table 3

Univariable Model to Predict Complications.

Variable	Odds Ratio	95% Confidence Interval	p Value
Alcohol abuse	0.560	0.159 - 1.97	0.37
Non-caucasian race	1.062	0.774 - 1.455	0.71
Age	1.037	1.015 - 1.060	0.001
Hypertension	1.491	0.886 - 2.509	0.13
Hypercholesteremia	1.274	0.747 - 2.171	0.37
Diabetes	1.087	0.606 - 1.949	0.78
Coronary artery disease	0.857	0.374 - 1.964	0.71
Congestive heart failure	0.669	0.142 - 3.164	0.61
COPD	2.126	0.837 - 5.399	0.11
Tobacco use	0.711	0.373 - 1.356	0.30
BMI	0.994	0.954 - 1.036	0.77
Albumin < 3.4 g/dL	1.886	0.941 - 3.781	0.07
Stair time	1.121	1.079 - 1.165	<0.0001

Table 4
Multivariable Model to Predict Complications

Variable	Odds Ratio	95% Confidence Interval	p Value
Age	0.997	0.971 - 1.023	0.81
Stair Time	1.110	1.064 - 1.159	<0.0001
Albumin < 3.4 g/dL	0.733	0.288 – 1.864	0.51
COPD	1.855	0.569 – 6.047	0.31
Hypertension	1.355	0.696 – 2.638	0.37