ESC European Society of Cardiology

European Heart Journal – Digital Health (2021) **2**, 77–87
doi:10.1093/ehjdh/ztab018

ORIGINAL ARTICLE

Reliability and repeatability of a smartphone-based 6-min walk test as a patient-centred outcome measure

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Received 12 October 2020; revised 28 December 2020; editorial decision 25 January 2021; accepted 3 February 2021; online publish-ahead-of-print 9 February 2021

Aims The 6-min-walk test (6MWT) is a validated proxy for frailty and a predictor of clinical outcomes, yet is not widely used due to implementation challenges. This comparative effectiveness study assesses the reliability and repeatability of a home-based 6MWT compared to in-clinic 6MWTs in patients with cardiovascular disease.

Methods and results One hundred and ten (110) patients scheduled for cardiac or vascular surgery were enrolled during a study period from June 2018 to December 2019 at the Palo Alto VA Hospital. Subjects were provided with an Apple iPhone 7 and Apple Watch Series 3 loaded with the VascTrac research study application and performed a supervised in-clinic 6MWT during enrolment, at 2 weeks, 1, 3, and 6 months post-operatively. Subjects also received notifications to perform at-home smartphone-based 6MWTs once a week for a duration of 6 months. Test–retest reliability of in-clinic measurements and at-home measurements was assessed with an industry standard Cronbach's alpha reliability test. Test–retest reliability for in-clinic ground truth 6MWT steps vs. in-clinic iPhone 6MWT steps was 0·99, showing high reliability between the two tested measurements. When comparing for in-clinic ground truth 6MWT steps vs. neighbouring at-home iPhone 6MWT steps, reliability was 0·74.

Conclusion Running the test–reliability test on both measurements shows that an iPhone 6MWT test is reliable compared to an in-clinic ground truth measurement in patients with cardiovascular disease.

Keywords Remote patient monitoring (RPM) • Six-min walk test (6MWT • Functional Capacity • Smartphone Activity Tracking

Introduction

The coronavirus disease 2019 pandemic has dramatically increased the implementation of telemedicine and heightened the need for reliable objective remote monitoring of patients with chronic diseases. Functional capacity has been shown to be an excellent indication of current health status and a valid predictor of outcomes,[1–5] but no reliable method for remote monitoring of functional capacity has

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been demonstrated. Functional capacity is patient-centred; for many patients, preserving functional capabilities, such as performing activities of daily living is more important than traditional disease-specific therapeutic endpoints, such as cardiac output or graft patency.[6] A recent study of over 96 000 participants from the UK Biobank study who had *1 week's worth of activity* tracking with a mean follow-up of 3 years showed a significant mortality benefit in those who demonstrated higher activity levels.[7] The gold standard for evaluating aerobic functional capacity is the assessment of cardiorespiratory fitness (CRF) as measured by the peak oxygen uptake during cardiopulmonary exercise testing (CPET). Other approaches include calculating metabolic equivalents (METs) during an exercise tolerance test (ETT) or having a patient perform a 6-min walk test (6MWT). All of these metrics have been shown to be accurate prognostic indicators for patients with coronary artery disease (CAD), arrhythmias, valvular heart disease, pulmonary hypertension, peripheral artery disease (PAD), and other cardiovascular diseases.[8] Cardiorespiratory fitness worsens with ageing and, when a patient is declining, CRF becomes the most significant risk factor for cardiovascular events.[6]

A variety of functional assessment tools are available, which include the gold-standard CRF tests as well as a less complex grip test, sit-to-stand-test, and questionnaires. Of the aerobic functional capacity tests, the 6MWT is the easiest and safest to administer while CPET and ETT require complex equipment and technical expertise to administer. In a 6MWT, patients are asked to walk up and down a 100-foot course for 6 min.[9] The total distance walked in metres is the result typically reported. The 6MWT is a submaximal exercise test that provides information regarding functional capacity, response to therapy, and prognosis across a broad range of chronic cardiopulmonary conditions. In heart failure patients, a 6MWT of <300 metres has been associated with frailty.[10,11] The main strengths of the 6MWT stem from its simplicity in concept, low cost, ease of standardization, and acceptance by test subjects including those who are deconditioned, elderly, or frail. However, the traditional 6MWT requires an in-person visit, a clinical technician to administer, and a marked hallway. As useful as it may be, these requirements limit clinical implementation and its use as a longitudinal metric of evaluation.

The increasing ubiquity of smartphones and smartwatches has sparked interest and research into the possibility of administering the home-based 6MWTs using smartphones and wearables.[12] Salvi *et al.*, for example, developed and evaluated indoor algorithm by detecting U-turns on a smartphone while performing a 6MWT on a standard course and an outdoor algorithm leveraging the smartphone's embedded GPS both to measure distance. They reported acceptable performance with maximal mean difference of only 2 m for the indoor algorithm and 0.8 m for the outdoor algorithm in two pulmonary hypertension patients and four healthy volunteers.[13] Moreover, at the most recent Worldwide Developer Conference, Apple announced that a passive 6MWT output would be provided by the Apple Watch after collection of 1 week's worth of data (https://developer.apple.com/videos/play/wwdc2020/10656/). However, the technology has yet to be evaluated in a peer-reviewed journal, leaving clinicians uncertain about how reliable these data will be. Our group previously studied the accuracy of an in-clinic smartphone-administered 6MWT in 114 patients with PAD and found iPhone steps count to have a bias of only -7.2% compared to ground-truth and a bias of only 5.7% with the research-grade Actigraphy GT9X Activity Monitor (Pensacola, FL, USA) pedometer. In contrast, we found a bias of 43% when comparing the iPhone Pedometer distance algorithm to in-clinic ground-truth measurements.[14] This finding prompted further research to assess the accuracy of home step count measurements from home-administered 6MWTs with a focus on 6MWT step counts. Such a tool would allow for real-world, patient-centred, objective, and longitudinal assessments of a patient's functional status. In this study, we aim to evaluate the reliability and repeatability of a home-based 6MWT. How does an in-clinic walk test compare to an at-home 6MWT?

Methods

Patients with cardiovascular disease that were still ambulatory (not wheelchair- or bed-bound) who were due to have cardiac or peripheral arterial interventions at the Palo Alto Veterans Affairs Hospital (PAVA) were identified and enrolled in our IRB-approved study. Study participants were provided an iPhone 7 and an Apple Watch Series 3. The watch and phone were equipped with the VascTrac research application developed by our research group (https://apps.apple.com/us/app/vasctrac/id1121791155). If the participant was unfamiliar with the devices, ~10–20 min was used to teach the patient basic phone/watch use and features. Of note, we did collect heart rate and activity data from the Apple watch; however, findings of these data will be published in future reports. Upon on-site enrolment, background information regarding the patient's medical, surgical, and walking history was obtained with the patient via in-app surveys (*Appendices 1–3*). The patient then completed an in-clinic supervised 6MWT administered on the iPhone following the ATS 6MWT protocol.[9] Study coordinators monitored each in-clinic 6MWT, counting steps using a handheld tally counter and recording distance walked similar to prior studies.[14] Participant complaints, such as leg cramping, limping, or shortness of breath, during the walk test were recorded. When the 6MWT was complete, subjects were asked to rest in a chair and answer post-walk questionnaires (*Appendices 4* and 5). The in-clinic 6MWT was repeated during scheduled follow-up visits at 2 weeks, and 1, 3, and 6 months. While at home, participants received a weekly phone notification from the VascTrac application to perform a home-based, smartphone-administered 6MWT. Patients received instructions to find an open space and perform the home 6MWT. Although patients did not have a marked course at home as they did in-clinic, the workflow of home 6MWT was otherwise the same as the in-clinic 6MWT. The study duration was 6 months. Test–retest reliability of in-clinic measurements and at-home measurements was assessed with Cronbach's alpha reliability test, which uses covariances between distributions to present an alpha, or correlation coefficient. The Cronbach's alpha that results from this assesses reliability through internal consistency of a set of items.

Results

One hundred and ten (110) patients with cardiovascular disease were enrolled at the PAVA between May 2018 and May 2019. There were 109 male participants (99%) with a mean age of 68.9 years (ranging from 57 to 89 years). The average BMI was 28.8 kg/m^2. Fifty-six patients (51%) were former smokers and 33 patients (30%) were current smokers. Ninety-four patients (85%) participants had hypertension, 39 (35%) had diabetes mellitus, 23 (21%) had aortic stenosis,

Table 1 Demographic characteristics of study participants

Physical characteristics	Mean ± SD *n* (%)	Co-morbidities	*n* (%)
Sex (male)	109 (99%)	PAD	69 (63%)
Age	68.9 ± 5.9	CAD	61 (57%)
Height (inches)	69.0 ± 3.4	Diabetes mellitus	39 (35%
Weight (lbs)	195.3 ± 40.4	Hypertension	94 (85%)
BMI (mean)	28.8 ± 4.7	Aortic stenosis	23 (21%)
BMI >30	40 (36 %)	Atrial fibrillation	16 (15%)
Current smoker	33 (30%)	Mitral stenosis	2 (2%)
Former smoker	56 (51%)	Mitral regurgitation	16 (15%)
Never smoked	12 (11%)	CHF	4 (3.9%)
Spouse/caregiver	73 (66%)	History of MI	4 (4%)
Smartphone naive	25 (23%)	ESRD	2 (2%)
Medications	*n* (%)	Total interventions	*n* (%)
Aspirin	92 (84%)	Peripheral arterial	59 (58.4%)
Plavix/clopidogrel	52 (47%)	PAD endovascular	41 (40.6%)
Statins	96 (87%)	PAD open	18 (17.8%)
Insulin	16 (15%)		
Warfarin	13 (12%)	Cardiac	42 (41.6%)
NOACs	11 (10%)	CABG/AVR	28 (27.7%)
Ankle brachial	Mean ± SD	TAVR	6 (5.9%)
index (ABI)			
Baseline ABI	0.73 ± 0.26	PCI	5 (4.9%)
Post-op ABI	0.88 ± 0.23	MVR	3 (2.9%)
Ejection fraction	% ± SD		
Baseline EF (%)	55 ± 10.3		
Post-op EF (%)	56 ±8.5		

Patient characteristics are listed in addition to select cardiovascular medications taken, incidence of peripheral artery disease (PAD), coronary artery disease (CAD), congestive heart disease (CHF), end stage renal disease (ESRD), history of myocardial infarction (MI), ankle brachial indices (ABIs), and ejection fraction (EF). Open peripheral arterial procedures include open bypass procedures or endarterectomies, while endovascular peripheral interventions include balloon angioplasty or stenting. Cardiac procedures include coronary artery bypass grafting (CABG), aortic valve replacement (AVR), mitral valve replacement (MVR), trans-aortic valve replacement (TAVR), and percutaneous coronary interventions (PCIs).

16 (15%) had atrial fibrillation, and 4 (4%) had heart failure. More patient characteristics and medication profiles can be seen in *Table 1*.

Patients underwent a total of 101 procedures. There were 59 peripheral arterial procedures (18 open bypass and/or endarterectomies and 41 endovascular procedures). There were 42 cardiac procedures (28 CABG/AVRs, 6 TAVRs, 5 PCIs, and 3 MVRs).

Out of the 110 study participants, there were 16 (15%) premature exits. There were 3 (3%) deaths prior to completing the study, 7 (6%) chose to withdraw, and 6 (5%) were lost to follow-up. Of the seven who withdrew, four were due to medical complications, one lost his devices, and two patients moved out of state.

Patients performed 445 supervised in-clinic 6MWTs and 2055 home 6MWTs. Walk tests with fewer than 50 steps were removed due to suspected errors in administration or likely interruption during administration. After removal of the walk tests, we were left with 444 supervised in-clinic 6MWTs (mean 4 in-clinic 6MWTs/patient; SD 1.50 6MWTs) and 2030 home 6MWTs (mean 18 home 6MWTs/patient; SD 10.17 6MWTs). The mean in-clinic phone, in-clinic ground truth, and home phone 6MWT step counts for all patients were 540.81 steps (SD 116.54 steps), 573.81 steps (SD 1118.41 steps) and 538.06 steps (SD 125.77 steps), respectively. The mean error between the in-clinic ground truth and in-clinic phone 6MWTs was ~5.6% over all 444 clinic walk tests (*Figure 1A*). The majority of patients averaged between 2% and 8% error between their ground truth steps and phone-calculated steps for in-clinic 6MWT (*Figure 1B*).

Of the 444 in-clinic 6MWTs, there were 288 neighbouring home walk tests (i.e. home 6MWT completed within 7 days prior or 7 days following clinic 6MWT). The mean difference or bias between in-clinic iPhone 6MWT step counts and home-based iPhone 6MWT step counts during this 14-day period was noted to be 35 steps higher in-clinic (95% CI -223.3 to 293 steps) (*Figure 2*). Most patients averaged <10% difference between their clinic step count (measured by phone) and neighbouring home step count (measured by phone; *Figure 3*). The mean differences or bias between in-clinic ground-truth 6MWT step counts and home iPhone 6MWT step counts during this 14-day period was noted to be 66 steps (95% CI -207 to 340 steps; *Figure 4*). Most patients averaged <20% difference between their clinic ground truth step count (measured by clinical coordinator) and neighbouring home step count (measured by phone; *Figure 5*).

When running the test–retest reliability test, we recorded a Cronbach's alpha between comparisons. Using this measure, test–retest reliability for in-clinic ground-truth 6MWT steps vs. in-clinic iPhone 6MWT was 0.99 (95% CI: 0.988–0.992). Test–retest reliability for in-clinic iPhone 6MWT steps vs. neighbouring at-home iPhone 6MWT steps was 0.74 (95% confidence interval: CI = 0.667–0.804).

Discussion

This study is the largest study evaluating the correlation between in-clinic 6MWTs (445) and self-administered home-based 6MWTs (2055). Our findings suggest that the iPhone captures 6MWT step counts that are consistent with supervised 6MWT step counts. High agreement is seen in both the in-clinic ground-truth 6MWT step count vs. in-clinic iPhone 6MWT results as well as the in-clinic iPhone 6MWT steps vs. the remote at-home iPhone 6MWT results. There is a small bias, or mean, of 43 greater steps in the preceding 7-day period and a 30-step bias in the following 7-day period for in-clinic ground truth compared to the remote at-home iPhone 6MWT when analysing all our patients with cardiovascular disease. A patient's functional capacity can also rapidly change week by week. Therefore, there is inherent variability even between in-clinic iPhone 6MWTs 2 weeks apart, and also can show up between in-clinic iPhone 6MWTs and at-home iPhone 6MWTs. However, these biases do not seem to be statistically significant given the high correlation coefficients. The test–retest reliability coefficient is greater than the 0.7 threshold expected for reliability.

Whenever home-based, patient-generated, measurements are made and variables cannot be fully controlled, algorithms must be developed to increase the confidence in the measurement. The Apple Watch's atrial fibrillation Irregular Rhythm Notification (IRN)

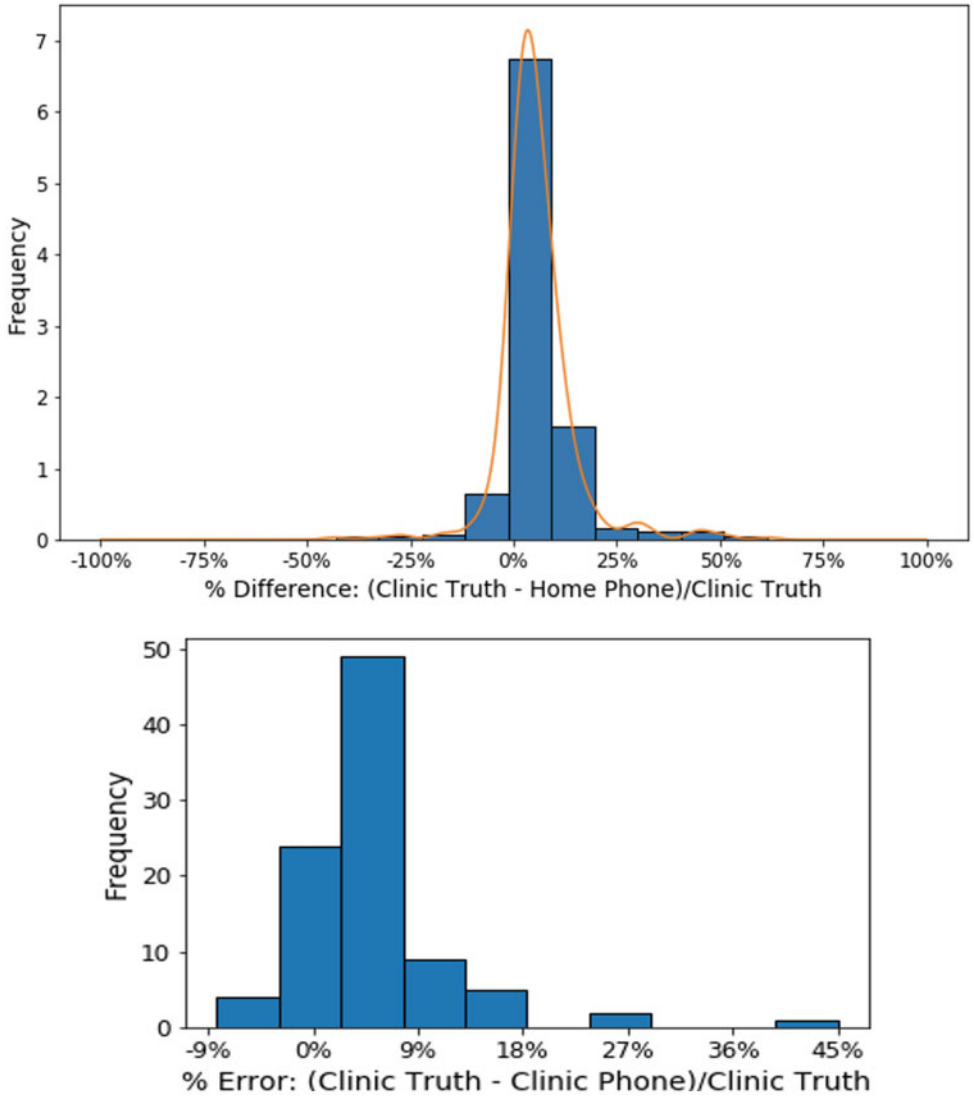


Figure 1 (*A*) (Top): Histogram of percent error between clinic ground truth steps and home phone steps for all clinic 6MWTs. Mean error = 0.056. (*B*) (Bottom): Histogram of average step count error per patient between clinic ground truth and clinic phone step counts.

algorithm, for example, requires 5 out of 6 tachograms within a 48-h period to be classified as irregular before an IRN is triggered.[15] In our study, all 6MWTs that were below 50 steps were filtered out as they were considered to be likely errors in implementation/administration or due to interruption of the patient during the 6MWT. In addition, at-home walk tests for each patient within the 14-day time span (7 pre- and 7 post-in-clinic walk) that were more than 2 SD below the clinic ground truth measurements were analysed for whether they were a true outlier. If the time duration of the at-home walk test differed significantly from the in-clinic ground truth time, then the at-home test was dropped based off of the conclusion that the test was accidentally started or stopped short. Implementing these inclusion criteria yielded the final walk tests that were used for test–retest reliability in order to prove internal and external reliability of our measurements.

We acknowledge that there are limitations to this study. First, nearly all of the patients enrolled in the study from the VA were male leading to gender bias. We believe that these results can still be generalizable given that the device will pick up mobility metrics regardless of gender, however, acknowledge that behaviours in smartphone use and carrying patterns could vary results. For example, women may carry their mobile device in a purse. We seek further validation in women. In addition, our implementation is limited to the Apple iPhone and would face major accessibility and adoption issues considering that Android is the major global mobile operating system.

Performing an at-home walk test reliably can be challenging. This is confirmed with the high test–retest reliability correlation of 0.99 between in-clinic ground truth step counts and in-clinic iPhone step counts, dropping to 0.74 when comparing clinic ground-truth to home iPhone step counts. Self-administration in addition to the

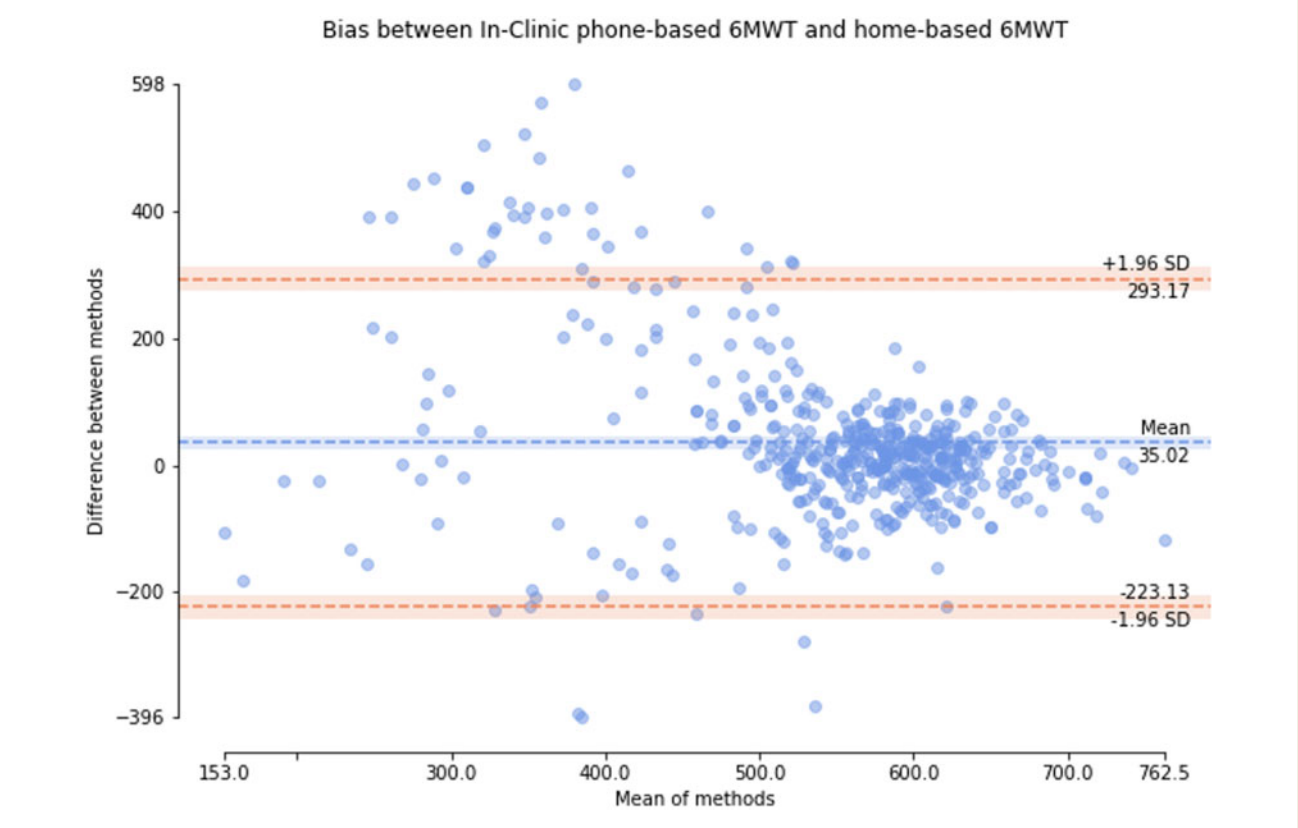


Figure 2 Bland–Altman plot demonstrating the mean difference or bias between in-clinic iPhone 6MWT step counts and home-based iPhone 6MWT step counts during this 14-day period was noted to be 35 steps (95% CI -223.3 to 293 steps). A mean of 35 more steps were counted in clinic compared to home measurements.

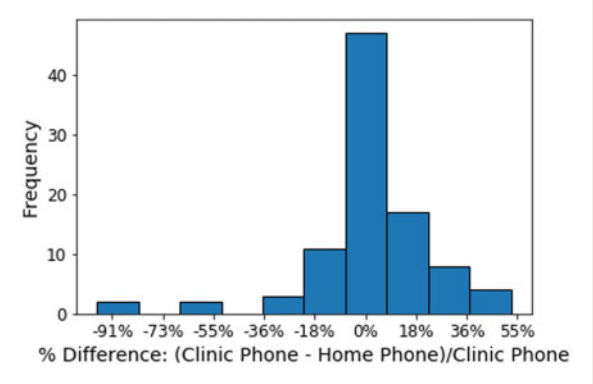


Figure 3 Histogram of average phone step count difference per patient between in-clinic 6MWT and neighbouring home 6MWT.

variable home environments led to a correlation drop of 0.25. Patients are self-administering the test and possible reasons may include but are not limited to: (i) technical issues with their mobile phone, (ii) interruptions during their walk by a friend, phone call, traffic, or weather, (iii) may have not chosen an appropriate location to perform an uninterrupted walk, or (iv) simply may have erroneously started a walk test on their phone. In addition, these tests were done one week apart, so inherent differences are inevitable. Improvements in implementation and further efforts to standardize and reinforce the home walk test protocol could further improve our test–retest reliability.

Overall, our patients were 75% compliant with their weekly home 6MWTs when receiving only an in-app VascTrac notification. A number of patients who had post-surgical complications could not complete their first post-operative home 6MWT for weeks and lowered overall compliance. Further engagement through phone calls or text messaging to trouble-shoot issues could improve overall compliance. Other contributing factors to missing home 6MWTs were weather and travel.

Six-min walk tests are typically reported as distance walked in metres. Our prior work showed significantly higher step count accuracy than distance accuracy, maintaining our focus on iPhone step counts measured during the 6MWT.[14] The cut-off for 6MWT distance in metres that is used to delineate patients as 'frail' has been reported as ≤300 m in patients with cardiac and peripheral vascular pathology.[16–19] Based on our 444 in-clinic ground truth distances, we estimate that 300 m correlates to 500 steps. For these 444 samples, using ≤500 steps as the 'frailty' cut-off predicts walk distances that

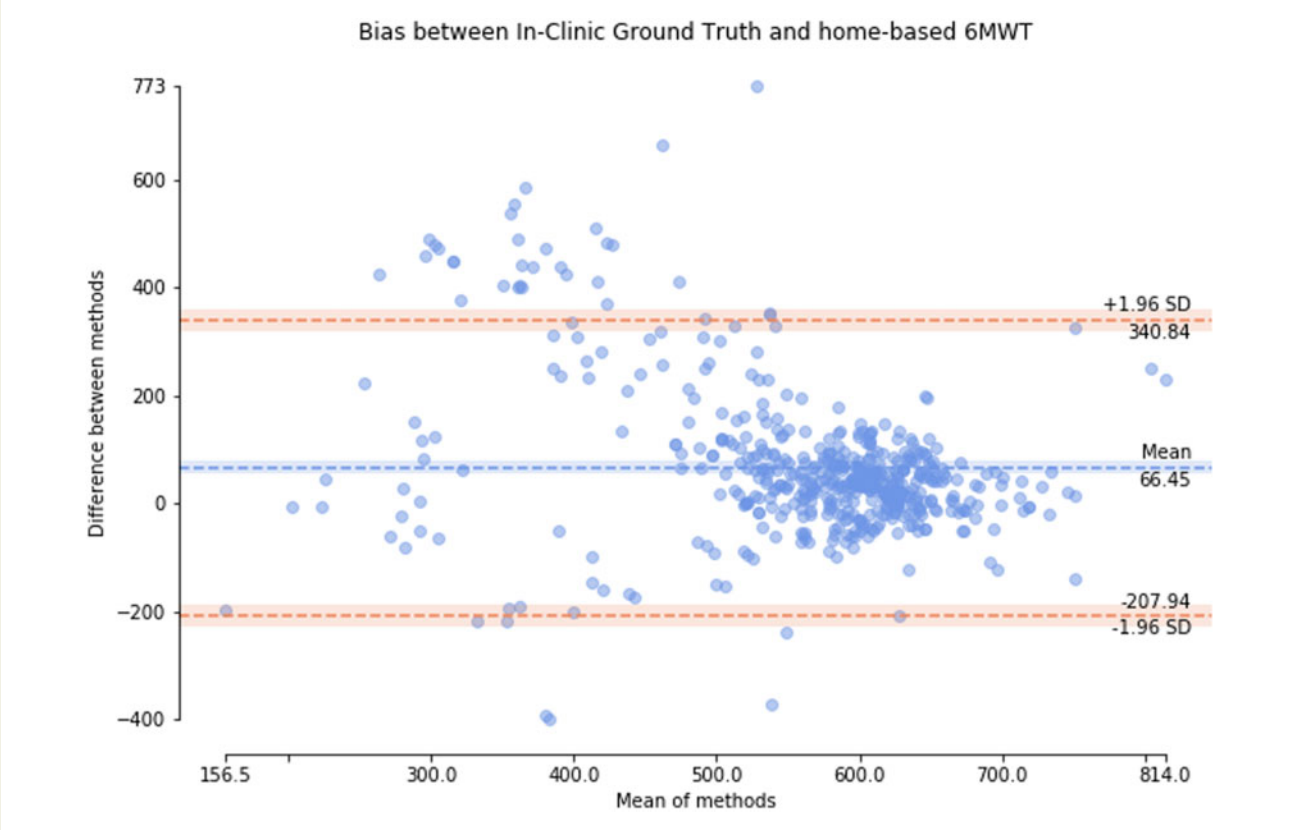


Figure 4 Bland–Altman plot demonstrating the mean differences or bias between in-clinic ground-truth 6MWT step counts and home iPhone 6MWT step counts during this 14-day period was noted to be 66 steps (95% CI -207 to 340 steps).

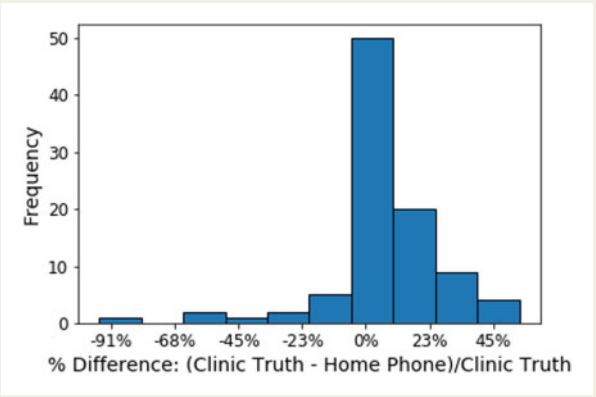


Figure 5 The difference between most patients averaged <20% between their clinic ground truth step count (measured by clinical coordinator) and neighbouring home step count (measured by phone).

were ≤300 m with a sensitivity of 0.69 and a specificity of 0.95. We calibrated the cut-off to optimize for higher specificity for 'frailty' because those classified as 'frail' will be discouraged from having invasive interventions. When using such analysis to determine who should receive further pre-intervention pre-habilitation, a 6MWT cut-off of 525 steps would be more appropriate (sensitivity 0.82 and specificity 0.87).

Conclusions

Clinically acceptable reliability and repeatability of a smartphone based 6MWT was achieved in patients with cardiovascular disease. An algorithm to filter errors in home self-administered 6MWTs was required to improve reliability. A cut-off of ≤500 steps from home 6MWTs in our study correlated with the ≤300 m traditionally used to categorize patients as 'frail' or high risk. The clinical validation of a patient-centred outcome measure, such as a smartphone based 6MWT has two overarching benefits. First, it allows us to objectively measure patients' real-world functional capacity in a continuous manner for pre-operative health assessments, response to therapy, and medical device decision making by FDA (https://www.fda.gov/about-fda/cdrh-patient-engagement/patient-reported-outcomes-pros-medical-device-decision-making, https://www.cms.gov/Research-Statistics-Data-and-Systems/Research/HOS). Second, it provides a clinically validated method to remotely monitor and engage in more meaningful telemedicine encounters. The first likely area of implementation of home 6MWT assessment will be for both cardiac rehabilitation programmes as well as home-based Supervised Exercise Therapy programmes for PAD as well as home-based surgical pre-habilitation programmes. All of these in-person programmes were shut down during the COVID-19 pandemic, highlighting the need and

urgency for the development of validated home-based programmes. Further studies to test and improve usability by patients and the acceptance by practitioners in clinical workflow are needed.

Acknowledgments

We thank the Cheryl Christianson of the Cardiac Surgery Service at the Palo Alto VA Health Care System for her support of this study. We would also like to thank Dexter Gormley for his contributions.

Funding

This work was supported by the Stanford Precision Health & Integrated Diagnostics (PHIND) Center Seed Grant and Apple Inc. Research Grant.

Authorship Contributions

Dasha Savage, Helle Nielse-Bowles, Doran Triggs, Julia Talgo, Neil Gandhi, Sebastian Gutierrez, Santiago Gutierrez: substantial contributions to the conception and design, acquisition of data, or analysis and interpretation of data

Jonathan Mak, Neil Rens, Oliver Aalami: Drafting the article or revising it critically for important intellectual content.

Conflict of interest: none declared.

Data availability

The VascTrac research application has been made open source and is available as part of Stanford's open source Cardinal Kit framework managed by the Stanford Biodesign programme. Please contact the authors to obtain access to a de-identified version of the data that supports the findings of this study through a data-use agreement.

Appendix

Appendix 1: Medical survey

1. Have you been diagnosed with PAD? REQUIRED
   - ● Yes
     - ○ What was your most recent ABI/TBI?
   - ● No
2. Have you been diagnosed with diabetes? REQUIRED
   - ● Yes
     - ○ Insulin dependent? REQUIRED
       - ■ Yes
       - ■ No
   - ● No
3. Have you been diagnosed with hypertension? REQUIRED
   - ● Yes
   - ● No
4. What is your most recent blood pressure?
   - ● Systolic: _ _ _ mmHg
   - ● Diastolic: _ _ _ mmHg
5. Have you been diagnosed with coronary artery disease (CAD)? REQUIRED
   - ● No
   - ● Yes
     - ○ Ejection fraction: ____ %
     - ○ Obstructive or non-obstructive
       - ■ Obstructive: How many vessels involved?
     - ● 1-vessel
     - ● 2-vessel
     - ● 3-vessel
       - ■ Any interventions?
     - ● PCI
     - ● CABG
     - ● None
6. Have you been diagnosed with congestive heart failure?

   REQUIRED
   - ● No
   - ● Yes
     - ○ Ejection fraction: ___ %
     - ○ New York Heart Association Functional Classification (Class I–IV)
       - ■ Class I: no limitation is experienced in any activities; there are no symptoms from ordinary activities.
       - ■ Class II: slight, mild limitation of activity; the patient is comfortable at rest or with mild exertion.
       - ■ Class III: marked limitation of any activity; the patient is comfortable only at rest.
       - ■ Class IV: any physical activity brings on discomfort and symptoms occur at rest.
7. Have you been diagnosed with aortic stenosis? REQUIRED
   - ● No
   - ● Yes
     - ○ Ejection fraction: ___ %
     - ○ Mean aortic valve gradient
       - ■ <25 mmHg
       - ■ 25–40 mmHg
       - ■ >40 mmHg
     - ○ Valve area
       - ■ >1.5 cm^2
       - ■ 1.0–1.5 cm^2
       - ■ < 1.5 cm^2
     - ○ Select symptoms (multiple possible)
       - ■ Angina
       - ■ Heart failure
       - ■ Syncope
8. Have you been diagnosed with atrial fibrillation? REQUIRED
   - ● No
   - ● Yes

     Atrial fibrillation class
       - ■ First detected (only one episode)
       - ■ Paroxysmal (recurrent episodes that stop on their own in < 7 days)
       - ■ Persistent (recurrent episodes that last >7 days)
       - ■ Permanent (an ongoing long-term episode)
9. History of smoking REQUIRED
   - ● Current smoker
   - ● Former smoker
   - ● Never smoked
10. Medications REQUIRED (select all)
    - ● Aspirin
    - ● Plavix/clopidogrel
    - ● Statin
    - ● Insulin
    - ● Warfarin/novel oral anticoagulant (NOAC)
    - ● None

Appendix 2: Surgical survey

1. Have you had any vascular procedures? REQUIRED
   - ● No
   - ● Yes
     - ○ Which procedures?

(Endovascular)
     - ■ Balloon angioplasty
     - ■ Stent
     - ■ Atherectomy
       - ● Procedure detail (free text field)
       - ● Date of surgery (date wheel)
       - ● Where are the arteries that were treated?
         - ○ Abdomen
         - ○ Left Leg
         - ○ Right Leg
       - ● Did you have another vascular procedure?
         - ○ Yes (goes back to beginning of surgical details for re-entry)
         - ○ No
     - ○ Which procedure?

(Open surgery-bypass or endarterectomy)
     - ■ Bypass surgery
     - ■ Endarterectomy
       - ● Procedure details (free text)
       - ● Date of surgery (date wheel)
       - ● Where are the arteries that were treated?
         - ○ Abdomen
         - ○ Left leg
         - ○ Right leg
       - ● Did you have another vascular procedure?
         - ○ Yes (goes back to beginning of surgical details for re-entry)
         - ○ No
2. Have you had a CABG or coronary artery stenting? REQUIRED
   - ● No
   - ● Yes
     - ○ CABG
       - ■ Date of surgery (date wheel)
       - ■ Procedure details
     - ○ Coronary artery stenting
       - ■ Date of surgery (date wheel)
       - ■ Procedure details
3. Have you had a heart valve surgery or TAVR? REQUIRED
   - ● No
   - ● Yes
     - ○ Date of surgery (date wheel)
     - ○ Procedure details

Appendix 3: Walking survey

1. Do you have painful cramping in the leg or thigh with activity? REQUIRED
   - ● No
   - ● Yes
     - ○ Does rest improve the pain? REQUIRED
       - ■ Yes
       - ■ No
       - ○ Does the pain come on every time you exercise? REQUIRED
       - ■ Yes
       - ■ No
     - ○ When do you get the pain? REQUIRED
       - ■ At rest
       - ■ In bed
       - ■ Sitting
       - ■ When walking
2. Do you get shortness of breath when walking? REQUIRED
   - ● No
   - ● Yes
     - ○ 1–10 scale (Revised Borg Scale)
3. Do you get chest pain when walking? REQUIRED
   - ● No
   - ● Yes
     - ○ 1–10 scale
4. Do you have any open wounds on your feet? REQUIRED
   - ● Yes
   - ● No
5. Do you experience any other pain while walking that may impair your ability to walk? (e.g. back or hip pain) REQUIRED
   - ● Yes
   - ● No
6. Are you able to walk up and down stairs (to the second floor) without help? REQUIRED
   - ● Yes
   - ● No
7. Are you able to walk a half mile without help? REQUIRED
   - ● Yes
   - ● No
8. Are you able to do heavy house work around the house (e.g. washing the windows, walls, floors) without help? REQUIRED
   - ● Yes
   - ● No
9. Do you use any walking aids? REQUIRED
   - ● Right hand cane
   - ● Left hand cane
   - ● Walker
   - ● Wheelchair
   - ● Other: _____ (free text)
   - ● None

Note: only one choice possible

If aide selected:

How often do you use walking aids on average? REQUIRED
   a. Daily
      i. <25% of the day
      ii. 25050% of the day
      iii. 75–100% of the day
   b. Less than daily (e.g. every other day, one day of the week, etc.)
   c. Very rarely (e.g. only during specific activities, sporadically as needed)
10. During the last year, have you involuntarily lost more than 10 lbs? REQUIRED
    - ● Yes
    - ● No
11. How often in the last week did you feel that everything you did was an effort or that you could not get going? REQUIRED
    - ● Rarely or sometimes (2 times or less per week)
    - ● Often or almost always (3 or more times per week)
12. What is your level of physical activity? REQUIRED
    - ● Regular physical activity (at least 2–4 h per week)
    - ● None or mainly sedentary

Appendix 4: Pre-walk test survey (not open walks)

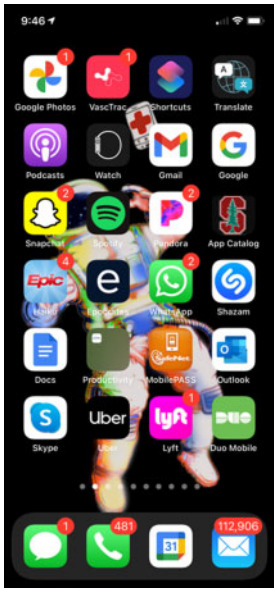
1. Do you get shortness of breath when walking? REQUIRED
   - ● No
   - ● Yes
     - ○ **1–10 scale (Revised Borg Scale)**
2. Will you be using any walking aids? REQUIRED
   - ● Right hand cane
   - ● Left hand cane
   - ● Walker
   - ● Wheelchair
   - ● Other: _____ (free text)
   - ● None

Note: only one choice possible

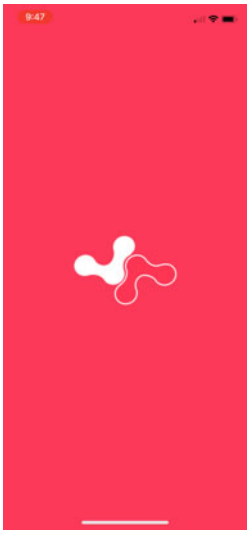
Appendix 5: Post-walk test survey

1. Please rate your current shortness of breath again on a scale of 0–10 REQUIRED
2. Did you experience any pain in the back, leg, hip, or other location that you feel may have impaired your ability to walk during this test? REQUIRED
   - ● No
   - ● Yes
     - ○ **Back**
     - ○ **Leg**
     - ○ **Hip**
     - ○ **Other:** _____
3. Have you experienced any injuries since your last walk test that has impacted your walking ability? REQUIRED
   - ● No
   - ● Yes
     - ○ Roughly how long ago did this occur?
       - ■ Yesterday
       - ■ 2 days ago
       - ■ 3 days ago
       - ■ 4 or more days ago
4. Where did you keep your phone during this walk test? REQUIRED
   - ● Right hand
   - ● Left hand
   - ● Right front pocket
   - ● Left front pocket
   - ● Right back pocket
   - ● Left back pocket
   - ● Bag/purse
   - ● Other: _____ (free text)

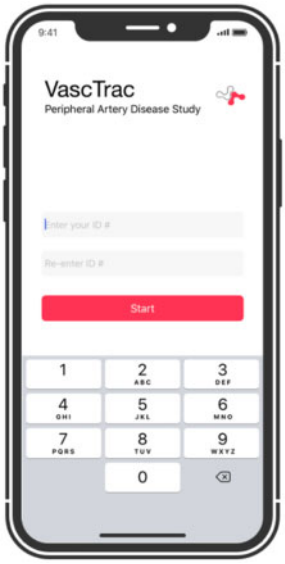
Appendix 6: VascTrac Screenshots & Link Study Website: http://vasctrac.stanford.edu/



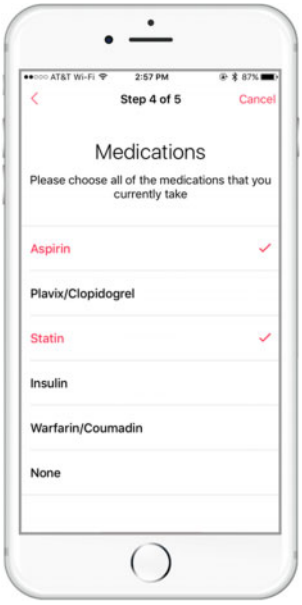
Application icon



Application splash screen

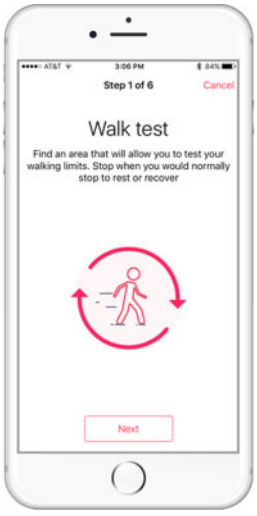


Application registration—done through an ID number provided to study participant.

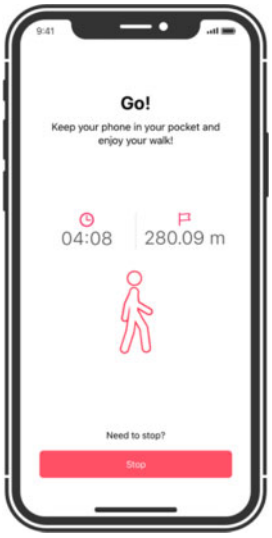


Sample medication survey.

Example of medical symptom survey question.



Six-min walk test prep-screen.



Six-min walk test screen.

Performance review dashboard.

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