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Global Positioning System Use in the Community to Evaluate Improvements in Walking After Revascularization

A Prospective Multicenter Study With 6-Month Follow-Up in Patients With Peripheral Arterial Disease

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Abstract: Revascularization aims at improving walking ability in patients with arterial claudication. The highest measured distance between 2 stops (highest-MD_{CW}), the average walking speed (average-WS_{CW}), and the average stop duration (average-DS_{CW}) can be measured by global positioning system, but their evolution after revascularization is unknown.

We included 251 peripheral artery diseased patients with self-reported limiting claudication. The patients performed a 1-hour stroll, recorded by a global positioning system receiver. Patients (n = 172) with confirmed limitation (highest-MD_{CW} <2000m) at inclusion were reevaluated after 6 months. Patients revascularized during the follow-up period were compared with reference patients (ie, with unchanged lifestyle medical or surgical status). Other patients (lost to follow-up or treatment change) were excluded (n = 89).

We studied 44 revascularized and 39 reference patients. Changes in highest-MD_{CW} (+442 vs. +13 m) and average-WS_{CW} (+0.3 vs. $-0.2\,km\,h^{-1}$) were greater in revascularized than in reference patients (both $P < 0.01$). In contrast, no significant difference in average-DS_{CW} changes was found between the groups. Among the revascularized patients, 13 (29.5%) had a change in average-WS_{CW}, but not in highest-MD_{CW}, greater than the mean + 1 standard deviation of the change observed for reference patients.

Revascularization may improve highest-MD_{CW} and/or average-WS_{CW}. This first report of changes in community walking ability in revascularized patients suggests that, beyond measuring walking distances, average-WS_{CW} measurement is essential to monitor these changes. Applicability to other surgical populations remains to be evaluated.

Registration: http://www.clinicaltrials.gov/ct2/show/NCT01141361

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Abbreviations: ABI = Ankle to brachial index, DS_{CW} = Stop Duration between walking bouts during Community Walking, GPS = Global Positioning System, MCII = Minimal clinically important improvement, MD_{CW} = Measured Distance in Community Walking between two symptom-limited stops. One patient may have multiple MD_{CW} in a 1 hour recording, MWD = Maximal Walking Distance, The absolute maximal distance walked before limb discomfort or pain forces the patient to stop, PAD = Peripheral Arterial disease, PASE = Physical Activity Scale for the Elderly, WIQ = Walking Impairment Questionnaire, WS_{CW} = Walking Speed During Community Walking: Mean walking speed between two stops during community walking.

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INTRODUCTION

Patients with intermittent claudication resulting from lower-extremity peripheral artery disease (PAD) report impaired walking ability, as can also do patients with lumbar spinal stenosis, lower-limb neuropathy or certain musculoskeletal conditions.[1,2] In claudication, the maximal walking distance (MWD) is defined by the distance covered before limb discomfort or pain forces the patient to stop walking. The MWD can be self-reported based on history (self-reported MWD) and estimated with questionnaires. In PAD, limitation can be subjectively estimated using the Walking Impairment Questionnaire (WIQ)[3,4] or objectively assessed on a treadmill (MWD-on-treadmill).[5] MWD-on-treadmill is the major outcome measure used to assess the effect of treatments on PAD patients with intermittent claudication.[6–8] Previous studies have shown that walking impairment can be assessed in PAD patients using global positioning system (GPS) recorders.[5,9–11] Interestingly, this technique allows for the measurement of the ‘‘highest measured distance between 2 stops during community walking’’ (highest-MD_{CW}), a parameter that correlates with measurements of MWD-on-treadmill[5] and with self-reported MWD.[12] However, the GPS-measured distance is 3 to 4 times greater than the self-reported distance or the distance measured on a treadmill. Furthermore, parameters other than highest-MD_{CW}, which are difficult to measure in the laboratory and are associated with walking impairment in PAD patients, can be analyzed with GPS.[11] Among these parameters are the average walking speed (average-WS_{CW}) of all walking bouts and the average duration of stops (average-DS_{CW}) between 2 bouts of symptom-limited community walking.[11] The duration of a walking stop has been shown to be a major determinant of immediately forthcoming walking ability.[10] However, to date, changes in highest-MD_{CW}, average-WS_{CW} and average-DS_{CW} have not been specifically studied in revascularized or reference patients (ie, an unchanged medical or surgical status).

We analyzed the following hypotheses: On average, highest-MD_{CW} and average-WS_{CW} would increase and average-DS_{CW} would decrease (for those patients who still had to stop) due to revascularization, whereas no change would be observed in the reference group; At the individual level, various walking strategies (ie, in walking speed and or in distance) would be observed among revascularized patients, with certain patients preferentially increasing their highest-MD_{CW} after revascularization, whereas other patients would preferentially increase their average-WS_{CW}. This point was of particular interest because if this hypothesis were true, the estimation of MWD alone with the usual tools could lead to underestimation of the functional benefit for those patients who increase their average-WS_{CW} rather than their highest-MD_{CW}; and WIQ-distance score changes and highest-MD_{CW} changes would be reasonably correlated together whereas a weaker correlation would be found between WIQ-speed score changes with average-WS_{CW} changes.

METHODS

The protocol was approved and monitored by the University Hospital of Angers (France) and performed according to the international ethics standards and the Declaration of Helsinki. The ‘‘Post-GPS’’ study was approved by the CPP-Ouest-II ethics committee and registered under the reference no. NCT01141361 (ClinicalTrials.gov). Twenty different physicians participated in the study (9 angiologists, 8 vascular surgeons, 2 cardiologists, and 1 rehabilitation physician). The present multi-center study is the second part of previously reported results on the applicability of GPS recording in clinical routine.[11]

Inclusion Criteria

Patients fulfilling the inclusion criteria (Table 1) were invited to participate. Patients provided written consent after being provided with oral and written information about the protocol.

TABLE 1. Inclusion and Exclusion Criteria

Inclusion criteria
Age >18 years old
Clinical stability of vascular-type intermittent claudication* in the last 3 months
Self-reported maximal walking distance ≤500 m
Ankle-to-brachial index at rest <0.90 or a history of lower limb revascularization
Absence of any systemic disease limiting exercise other than claudication
Absence of myocardial infarction in the last 6 months
Absence of heart disease requiring surgery
Absence of angina pectoris
Absence of sustained ventricular arrhythmias
Absence of abdominal aortic aneurysm >40 mm
Absence of uncontrolled hypertension
Exclusion criteria
Highest GPS-measured distance in the community not available or >2000 m at T0
Missing data for the GPS recording at 6 months
Modified treatment other than lower limb revascularization

* Vascular-type intermittent claudication was defined as limb fatigue, discomfort, or pain that did not exist at rest, that occurred during walking, that forced the individual to stop and that resolved within 10 minutes of rest.

Procedures

We recorded the characteristics of each patient, including gender, age, stature, body weight, the ankle-to-brachial index (ABI; lowest right or left ABI, with ABI calculated as the highest ankle value divided by the highest arm pressure) and self-reported MWD. Thereafter, patients were provided clinical questionnaires that included specific items asking about their medical and surgical histories and ongoing medication, in addition to the Physical Activity Scale for the Elderly (PASE) questionnaire and the WIQ.[3,4] Lastly, patients were given oral and written walking (Figure 1) and technical instructions as well as a GPS device to record a 1-hour outdoor stroll in the community. To avoid any confusion between the walking ability measured by the questionnaires and the ability measured by GPS, the outdoor community walk is referred to as a ‘‘stroll’’ throughout this paper, although patients were asked to walk at a regular pace. A pre-stamped envelope was provided to each patient to return the questionnaires and the GPS device to the coordinating center after the stroll. As previously reported,[5,10,14] we used DG-100 GPS data loggers and the AT-65 GPS Active Antenna (GlobalSat Technology Corp., New Taipei City, Taiwan) that included the ‘‘European Geostationary Navigation Overlay Service’’ function. The recording rate was preset to 0.5 Hz. Patients only had access to the start and stop buttons of the recorder. Patients were asked to walk at their usual pace for 1 hour on a flat area free of compact trees or buildings. They were instructed to stop only because of lower limb pain and not necessarily to wait for the pain to disappear before beginning walking again.

GPS Analysis

Validation of the use of the GPS technique to analyze walking parameters in healthy and PAD patients has been reported elsewhere.[10,14] In brief, GPS-derived parameters included the total distance walked, the total duration of the walk (including the stop duration), the number of stops, highest-MD_{CW}, average-WS_{CW} and average-DS_{CW}. A technically satisfactory recording was defined as[11]: a total walk duration >30 minutes, the presence of recorded data in the GPS device, and the presence of identifiable periods of walking (a succession of periods of displacement compatible with walking, that is, with speeds between 1 and 10 $km\,h^{-1}$ and with durations of at least 10 seconds). At time-0 (T0) and time-1 (T1), if the recording was not technically satisfactory, a second attempt was performed within a month of the first attempt.

Follow-up, Exclusion Criteria and Inter-Current Events

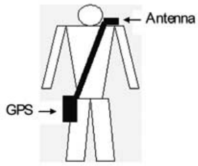
Please note that the study is not randomizing patients into different treatment groups but just observing what happened over the follow up period. Following the initial 1-hour stroll

INSTRUCTIONS FOR THE WALK

We thank you for kindly agreeing to participate in the POST-GPS study.
You must be currently sitting or standing still close to a chosen location that is close to a river, seaside, public park, athletic running track, pedestrian field, etc.). Please note that the second stroll should be performed at the same place as the first one. Please take a few minutes to completely read the following instructions.

Take the GPS device in its sealed plastic bag. Without opening the sealed bag, press and hold the large white button. A green LED should light up. This means that the GPS is on. Please do not turn off the GPS. It will stop automatically.

Place the strap as shown in this figure over your coat, with the antenna (small black cube) on the top of your shoulder. The GPS device should be around the belt, as in the adjacent figure. Please remain seated or standing (not walking) for a few minutes (10 minutes is optimal) in order to read the following instructions.



We would like to remind you that:

- Once the GPS is turned on, you should wait for 10 minutes before starting your walk.
- You should walk at your usual walking pace. Do not walk slowly to try to avoid stop periods or at a forced pace.
- The walk should last 1 hour (excluding the initial waiting period of 10 min).
- Please do not stop as soon as pain occurs: only stop when pain becomes unbearable.
- You can re-start the walk whenever you want after a stop period.
- The stop durations are included in the total one-hour walk.
- Please do not stop to look at the landscape or other things. All your stops should be due to walking-induced limb pain.
- You can be accompanied by a relative or a friend, provided that you walk at your own pace.
- Please do not walk with a dog.

It probably took you 2 to 3 minutes to read this text. This may not be enough time to obtain an accurate signal for the GPS to be ready for recordings (flashing green LED). Even if the GPS seems ready, please wait for a few more minutes (a total of 10 minutes) and then enjoy your walk.

KEY POINTS

1. To start the GPS, press the large grey button for 4 to 5 seconds until the LED lights up.
2. If the LED does not light up, there might be a plastic strip protecting the batteries inserted on the side of the sealed plastic bag containing the GPS. If so, gently pull it off and try to start the GPS again.
3. Wait until the green LED flashes.
4. If, after 5 minutes of waiting, the green light does not flash:
   a. Turn off the GPS by pressing the grey button once again for 4 to 5 seconds.
   b. Move 10 m away from the initial waiting spot.
   c. Turn on the GPS again and wait again for the green LED to flash.
5. If the green LED still does not flash after 5 minutes, please contact us at the following number: (*Number hidden for publication*).
6. One the GPS is ready, please wait for 10 minutes with the green light flashing before starting your one-hour walk.
7. Please walk for at least one hour at your own pace. Stop only because of your usual walking-induced pain.
8. At the end of your walk, please wait for at least 2 minutes at the same place before leaving the test area where you walked.

FIGURE 1. English translation of the recto-verso recommendation sheet provided to each patient for the stroll.

(T0), patients for whom a technically satisfactory GPS recording was not available at T0 or who had GPS recording results that were inconsistent with walking limitations (ie, highest-MD_{CW} >2000 m) were excluded. Patients with a successful T0 measurement underwent a second test 6 months later (T1). T1 was eventually delayed to allow a minimum of 3 months to elapse after any surgical or medical event (e.g., revascularization, change in treatment, non-vascular surgery, infraction, and stroke). For the T1 test, the participating patients were recommended to follow the same instructions as for the first test. Following the walk at T1, these patients were asked to complete items on whether they had to stop for any reason other than limb pain (e.g., dyspnea, road crossing, tying shoelaces, urinating, etc.), whether or not they experienced lower limb pain during the walk. Finally, patients for whom no technically satisfactory GPS recording could be obtained after 2 attempts at T1 were also excluded from the study.

Analysis of Data

Patients were classified into the following groups based on treatments or medical status changes that occurred over the study follow-up period: i) revascularized patients were patients who had any type of lower-limb arterial surgery or angioplasty between T0 and T1; ii) reference patients were patients who had no apparent changes in their treatments or medical status and no revascularization procedures between T0 and T1; and iii) patients who had any type of medical or non-vascular surgical intervention between T0 and T1 (e.g., bone or spine surgery, rehabilitation program, modification of cardiovascular drug regimen) were excluded from the study. Excluded patients with available T0 and T1 tests ($n = 32$) are described in Supplemental Digital Content 1, http://links.lww.com/MD/A265.

Statistical Analysis

The normality of distribution was first assessed for variables of interest using the Kolmogorov-Smirnov test. For continuous variables, the data are expressed as the mean ± stan-standard deviation (SD) for normally distributed variables and as the median [25th;75th percentiles] for non-normally distributed variables. For categorical variables, the data are expressed as numbers and percentages. Accordingly, for continuous variables, between-group differences were examined using paired-*t* tests (normally distributed variables) or a Wilcoxon test (non-normally distributed variables). For categorical variables, Fisher's exact test was used to assess differences between groups.

We referred to the mean + 1 SD of the changes observed in the reference group to detect meaningful improvements (ie, minimal clinically important improvement: MCII)[15] in highest-MD_{CW}, average-WS_{CW}, WIQ-distance and WIQ-speed among the revascularized compared with the reference patients. The concordance between GPS changes and WIQ changes in speed or distance were analyzed with linear regression analysis and Pearson's coefficient of correlation. For all statistical tests, a 2-tailed probability level of $P < 0.05$ was used to indicate statistical significance. SPSS (V15.0 SPSS Inc., 2004) was used for all statistical analyses. The study was designed to include 250 patients, assuming that nearly half of the patients would have no limitations while walking at T0, would be lost to follow-up, or would have unsatisfactory recordings. We also expected that at least one-third of the patients would undergo revascularization during the follow-up period.

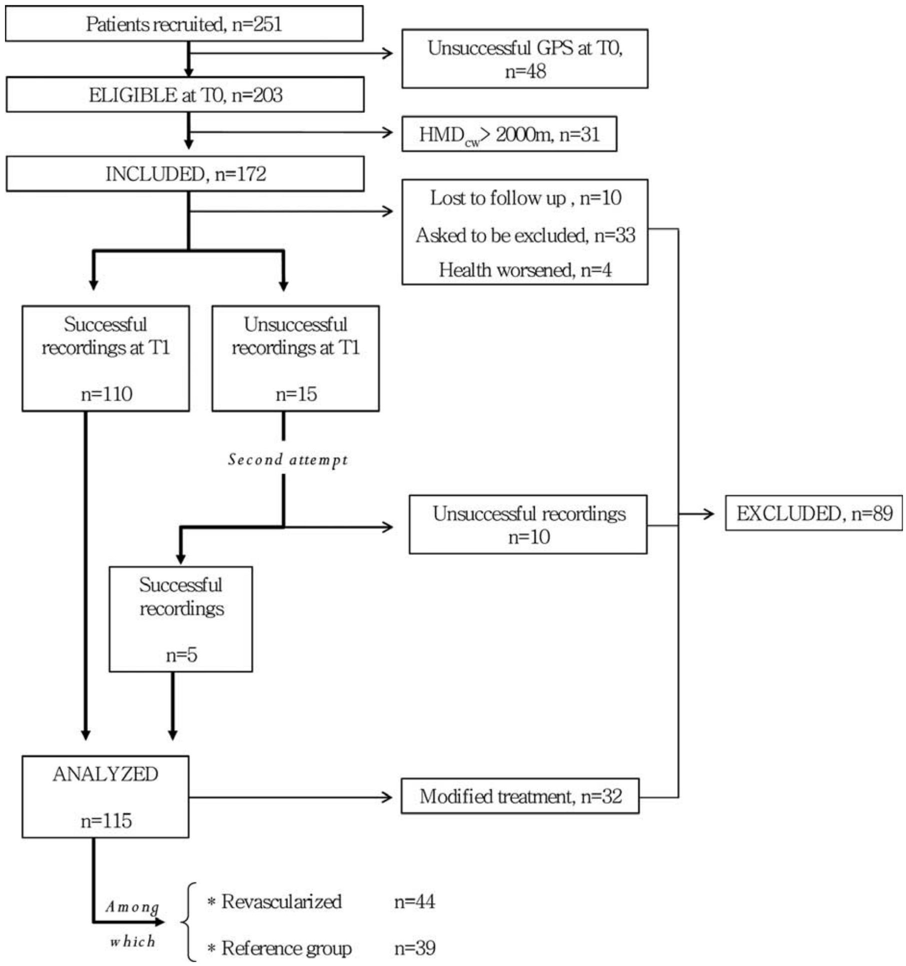


FIGURE 2. Flow diagram of the patients, with the corresponding numbers of technically satisfactory GPS recordings and the causes of technically unsuccessful GPS recordings.

RESULTS

Population Description

Of the 251 included patients, only 172 had limitations confirmed with GPS at T0 (79 exclusions). Among these 172 patients, 57 patients were excluded, mostly because they refused to perform the second test at T1, and another 32 were excluded because they could not be classified in the reference group because they had no revascularization but changes in medical, lifestyle or non-vascular surgical status between T0 and T1 (Figure 2). The clinical characteristics and results of the included patients at T0 are presented in Table 2. Note that the ABI was missing for 14 patients, either because ''non-measurable pressure'' or ''incompressible arteries'' were noted or, in 1 case, because of values that were missing from the data file. Of the 83 studied patients, 44 underwent revascularization (24 had angioplasty, and 20 had surgery) between T0 and T1 (Table 3). The median time interval between revascularization and T1 was 143 [110;176] days. In total, 39 patients reported no revascularization and no significant changes in treatments, rehabilitation or smoking habits between T0 and T1 (reference patients). Additionally, as shown in Table 2, no differences were found between revascularized and reference patients at T0. Thus, no adjustment was required in further analyses of changes in GPS parameters or other functional parameters between T0 and T1. As is also shown in Table 2, few PASE and WIQ questionnaires could not be scored despite the use of pre-defined rules to account for missing answers,[3,4] because the patients had not filled out the questionnaires adequately.

GPS Results

Two typical examples of GPS recordings, 1 in a patient who experienced revascularization and in a reference patient, are presented in Figure 3. Figure 3 illustrates the variability in walking bouts and stop durations observed at T0 and T1 and provides the values of highest-MD_{CW}, average-DS_{CW} and average-WS_{CW}. As shown, important variability existed in the peak distances before each stop and in the stop durations during each stroll, whereas walking speed (which can be visually estimated from the slope of each walking bout) remained relatively stable throughout the different walking periods during the stroll. The revascularized patient (upper panel) had circled around 2 football fields. After revascularization, both highest-MD_{CW} and average-WS_{CW} increased, whereas average-DS_{CW} decreased at T1 compared with T0.

TABLE 2. Characteristics of the Patients at Inclusion (T0)

	Revascularization Group	Reference Group	$P^{\#}$
Characteristics			
Males/females	39/5 (n = 44)	39/0 (n = 39)	0.7023
Age (years)	62.9 ± 9.4 (n = 44)	66.2 ± 9.6 (n = 39)	0.1280
T1-to-T0 interval (months)	8.2 ± 2.3 (n = 44)	7.9 ± 2.3 (n = 39)	0.5861
Stature (cm)	170 ± 7 (n = 42)	169 ± 5 (n = 39)	0.5992
Weight (kg)	78.3 ± 12.8 (n = 42)	78.2 ± 11.3 (n = 39)	0.9686
Self-reported–MWD (m)*	279 ± 208 (n = 42)	291 ± 153 (n = 38)	0.7776
Ankle-to-brachial index	0.61 ± 0.18 (n = 41)	0.66 ± 0.22 (n = 39)	0.4722
Ongoing medications			
Antiplatelet n (%)	32 (73%) (n = 44)	36 (92%) (n = 39)	0.4666
Antidiabetic n (%)	19 (43%) (n = 44)	16 (41%) (n = 39)	0.8992
Antihypertensive n (%)	28 (64%) (n = 44)	23 (59%) (n = 39)	0.8313
Beta-blockers n (%)	9 (20%) (n = 44)	16 (41%) (n = 39)	0.1358
Other cardiac drugs n (%)	12 (27%) (n = 44)	9 (23%) (n = 39)	0.7344
Cholesterol-lowering drug n (%)	33 (75%) (n = 44)	34 (87%) (n = 39)	0.6471
GPS results			
Total walking time (min)	63.9 ± 7.3 (n = 44)	64.2 ± 8.1 (n = 39)	0.8371
Total distance (m)	3917 ± 938 (n = 44)	3124 ± 842 (n = 39)	0.5888
Number of stops	10 ± 7 (n = 44)	9 ± 6 (n = 39)	0.7557
Highest-MD_{CW} (m)†	709 ± 477 (n = 44)	790 ± 482 (n = 39)	0.4423
average-WS_{CW} (km/h)‡	3.5 ± 0.6 (n = 44)	3.5 ± 0.6 (n = 39)	0.8844
Average-DS_{CW} (min)§	1.74 ± 1.16 (n = 44)	1.52 ± 1.36 (n = 39)	0.4366
Questionnaires			
PASE score‖	126.8 ± 71.8 (n = 30)	115.3 ± 63.6 (n = 31)	0.5099
WIQ-speed sub-score¶	33.7 ± 16.8 (n = 42)	38.1 ± 18.9 (n = 36)	0.2885
WIQ-stairs sub-score¶	38.5 ± 17.1 (n = 43)	45.5 ± 28.7 (n = 35)	0.1860
WIQ-distance sub-score¶	34.6 ± 19.6 (n = 31)	39.9 ± 18.4 (n = 35)	0.1525

The number of available values is reported in the case of missing data.
* Self-reported–MWD is the maximal walking distance reported by the patient.
† Highest-MD_{CW} is the highest measured distance measured by GPS.
‡ average-WS_{CW} is the average walking speed measured by GPS.
§ average-DS_{CW} is the average duration of stops measured by GPS.
‖ PASE is the Physical Activity Scale for the Elderly.
¶ WIQ is the Walking Impairment Questionnaire.
\# *P* is the Wilcoxon coefficient of correlation.

The reference patient (lower panel) walked along a lake during both strolls. Of interest is the fact that during T1, the patient B stopped multiple times for very short durations but covered a relatively long distance when the previous stop was long enough.

TABLE 3. Type of Revascularization Occurring Between T0 and T1 Among Patients in the Revascularization Group

Type of Revascularization	N (%)
Surgery	20 (45.5%)
Angioplasty	24 (54.5%)
Level of the revascularization	
Femoro-popliteal	11
Aorto-iliac	32
Infra-popliteal	1

The number of patients as well as the percentage are reported in the case of missing values.

Average Changes Between T0 and T1

Changes in walking limitations that were estimated by the questionnaires and measured by GPS are reported by group in Table 4. As shown, for nearly all questionnaire results, the differences observed in revascularized patients were significantly higher than those found in reference patients. For GPS, the increases in highest-MD_{CW} and average-WS_{CW} were significantly higher in revascularized than in reference patients. However, although the decrease in average-DS_{CW} was nearly 2 times higher in revascularized than in reference patients among those patients who still had to stop at T1, this difference did not reach statistical significance ($P = 0.0767$).

Individual Changes Between T0 and T1

When using the mean + 1 SD of the changes in the reference group as limits for the detection of MCII among the 44 revascularized patients, 13 patients (29.5%) had MCII in both highest-MD_{CW} and average-WS_{CW}, 3 patients (7%) had MCII in highest-MD_{CW} but non-improved average-WS_{CW}, and 13 (29.5%) patients had MCII in average-WS_{CW} but not

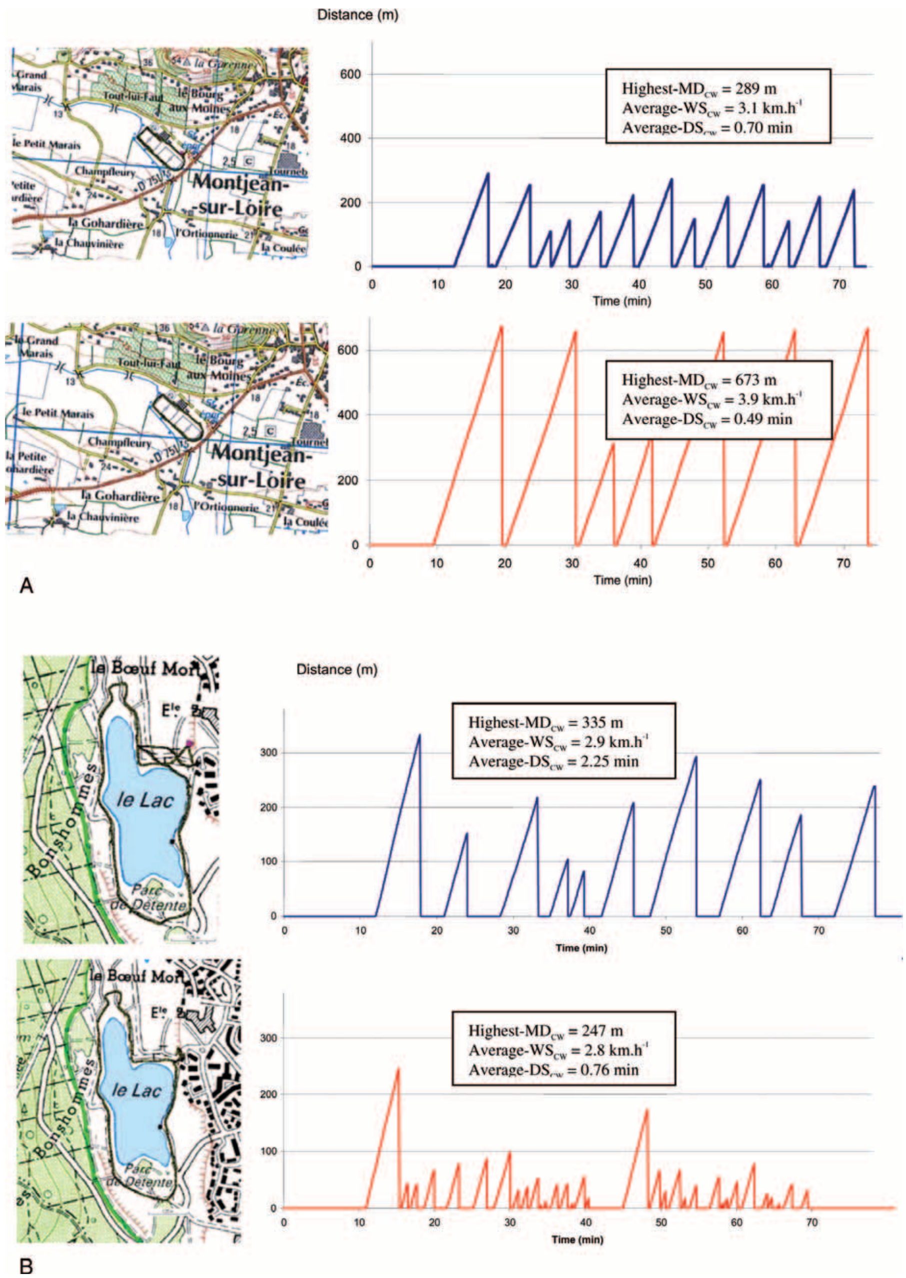


FIGURE 3. Typical recordings of the distance covered during each walking bout at T0 (upper panels) and T1 (lower panels) for 1 revascularized patient (A) and 1 reference patient (B).

highest-MD_{CW}. The other 15 patients (34%) had no MCII in either the average-WS_{CW} or highest-MD_{CW} compared with the reference patients, as shown in Figure 4 (upper panel). However, among the 37 revascularized patients with available data for WIQ distance and speed sub-scores, 2 (5.5%) patients had MCII in both the WIQ distance and speed sub-scores, no patient (0%) had MCII in only the WIQ distance sub-score, and 10 (27%) patients had MCII in the WIQ speed sub-score but not the WIQ distance sub-score. The other 25 patients (67.5%) had no MCII in either the distance or the speed WIQ sub-scores compared with reference patients, as shown in Figure 4 (lower panel).

Concordance of GPS and Questionnaire Changes

Finally, the correlation of highest-MD_{CW} changes with WIQ-distance changes was statistically significant in the patients who had all data available ($n = 96$, $r = 0.599$; $P < 0.001$). The correlation of average-WS_{CW} changes to WIQ-speed changes was also significant ($n = 102$, $r = 0.394$; $P < 0.001$).

DISCUSSION

Isolated case reports using GPS after spine surgery[16] or amputation[17] have recently been published. To the best of our

TABLE 4. Walking Capacity Changes Between T0 and T1 Among the 83 Studied Patients (Revascularised Group vs. Reference Group)

	Revascularization Group (n = 44)	Reference Group (n = 39)	$P^{\#}$
Hemodynamic changes			
Ankle-to-brachial index	+0.22 ± 0.26 (n = 37)	−0.01 ± 0.19 (n = 31)	0.0004
GPS changes			
Total walked time (min)	−2.55 [−6.39;+0.43]	−3.90 [−7.86;+3.29]	0.3727
Total walked distance (m)	+455 ± 786	−181 ± 561	0.0001
Number of stops per hour	−5 ± 5	+1 ± 7	<0.0001
Highest-MD_{CW} (m)*	+442 [+213;+2474]	+13 [-218;+561]	0.0006
Average-WS_{CW} ($km \cdot h^{-1}$)†	+0.3 ± 0.5 (n = 44)	−0.2 ± 0.4 (n = 39)	0.0004
Average-DS_{CW} (min)‡	−0.81 ± 1.34 (n = 44)	−0.26 ± 1.43 (n = 39)	0.0767
Questionnaire changes			
PASE score§	+10.7 ± 84.8 (n = 23)	+10.5 ± 62.2 (n = 33)	0.9425
WIQ average score‖	+31.1 ± 22.0 (n = 38)	+3.0 ± 14.4 (n = 33)	<0.0001
WIQ-speed score	+24.8 ± 21.7 (n = 37)	+1.9 ± 17.0 (n = 34)	<0.0001
WIQ-distance score	+40.8 ± 29.8 (n = 37)	+4.5 ± 25.0 (n = 33)	<0.0001
WIQ-stairs score	+26.5 ± 24.5 (n = 36)	+3.8 ± 14.5 (n = 33)	<0.0001
Self-reported MWD (m)¶	+400 [+200;+700] (n = 43)	0 [-50;+130] (n = 37)	<0.0001

Data expressed as median [25th;75th percentiles] or mean ± SD. The number of available values is reported between parentheses in the case of missing data.
* Highest-MD_{CW} is the highest measured distance measured by GPS.
† average-WS_{CW} is the average walking speed measured by GPS.
‡ average-DS_{CW} is the average duration of stops measured by GPS (Calculated only for patients with at least 1 stop at T0 and T1).
§ PASE is the Physical Activity Scale for the Elderly.
‖ WIQ is the Walking Impairment Questionnaire.
¶ MWD is the maximal walking distance.
\# P is the Wilcoxon coefficient of correlation.

knowledge, this is the first prospective multicenter study using GPS for the follow-up of revascularized and reference patients.

Many studies have analyzed the changes in MWD-on-treadmill or the changes in the WIQ score after revascularization, with results ranging from 163%[18] to 176%[19] and from 37%[20] to 203%,[21] respectively, but the correlation coefficient between the change in the total WIQ score and changes in MWD-on-treadmill has previously been reported to be low ($r = 0.331$).[22] Additionally, we previously reported that self-reported MWD correlates fairly well with community-based measurements (ie, highest-MD_{CW}), as assessed by GPS,[12] even though highest-MD_{CW} determined by GPS generally ranges around 3 times higher than self-reported MWD.[5,10,12] Consistent with our previous observation,[10] a wide variability of distances and stop durations were observed within a single stroll for each patient in the current study, whereas speed remained relatively stable (Figure 3). These findings explain our interest in studying highest-MD_{CW}, average-WS_{CW} and average-DS_{CW}. However, no study to date has simultaneously and separately analyzed changes in highest-MD_{CW}, average-WS_{CW} and average-DS_{CW} after surgery, specifically after revascularization. We report here for the first time that after revascularization, more than one-third of patients appear to improve their speed rather than their distance. This result is of major importance because usual walking speed improvement in the community is rarely studied or measured.

Walking speed has rarely been objectively measured in PAD patients with claudication, despite the well-known decrease in velocity in PAD compared with non-PAD patients,[23,24] and despite the inverse relationship that exists between walking distance and walking intensity in claudicants.[25,26] It has been shown that women with PAD have a slower walking speed than men do[27] and that following revascularization, the WIQ-speed sub-score improves by 18.6%[20] to 130%.[21] Unlike distance, although significant, the correlation of the WIQ-speed subscore to average-WS_{CW} changes was fair in the present study, suggesting that self-reported responses cannot reliably estimate changes in average-WS_{CW}. Specifically, very few patients reported isolated speed improvement on the WIQ questionnaire, whereas GPS results suggested that more than one-third of patients had MCII in the average-WS_{CW} without improvement in the highest-MD_{CW}. One explanation could be that GPS underestimates the distance improvement in such patients. Another possibility could be that WIQ-distance changes and WIQ-speed changes are not sufficiently independent of one another to assess speed and distance changes separately. Many studies using the WIQ have shown that both the WIQ-speed and the WIQ-distance scores improved after revascularization,[18,20–22] but no previous study has analyzed the relationship between measured distance changes and measured speed changes.

Whether certain patients preferentially maintain a constant speed and improve their distance, whereas others increase their walking speed rather than their maximal walking distance, is unknown. Furthermore, no previous study has confirmed these changes using objective measurements. Clearly, in the present study, many more patients had an MCII according to the GPS-derived highest-MD_{CW} result than according to the WIQ-distance. The issue of speed and/or distance changes while walking is of major interest not only in revascularized patients but also in

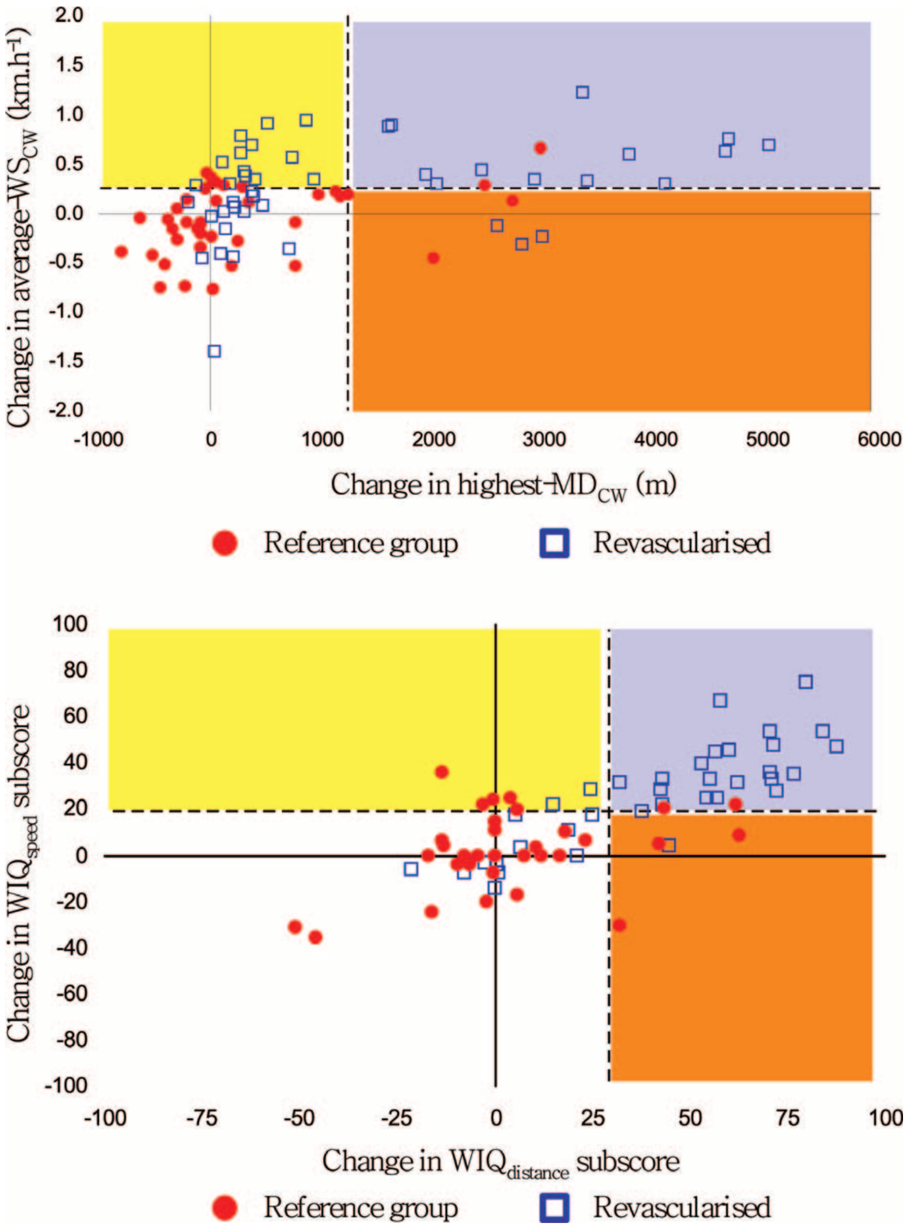


FIGURE 4. Changes in walking speed (average-WS$_{CW}$) and the highest measured distance (highest-MD$_{CW}$) during a community walk among reference (red dots) and revascularized patients (blue squares). The dashed lines represent the mean + 1 SD of changes needed to detect MCII compared with reference patients. Yellow square: average-WS$_{CW}$ or WIQ-speed improved only; Orange square: highest-MD$_{CW}$ or WIQ-distance improved only; Purple square: Both average-WS$_{CW}$ and highest-MD$_{CW}$ or both WIQ-speed and WIQ-distance improved; White square: No MCII.

the evolution of PAD in patients. Indeed, in addition to hemodynamic tests, the gold standard for estimating the worsening of PAD is a decrease in MWD. Nevertheless, it is probable that certain patients progressively and unconsciously decrease their community walking speed, while their distance walked remains stable. At worst, the speed decrease could be so extreme that the patients remain asymptomatic while walking. Together with the decrease in lifetime recreational activity in PAD patients,[28] this phenomenon could lead to patients remaining asymptomatic while their disease progresses. This situation might explain why the general prognosis of asymptomatic PAD patients is worse than that of symptomatic PAD patients.[29] Walking speed for short walking bouts can be estimated using the time required to walk a fixed 4 m[1,2,30,31] at the usual pace in a corridor, but there is no evidence that this laboratory measurement correlates to average-WS$_{CW}$.

We initially expected average-DS$_{CW}$ to be an index of improved perfusion in revascularized patients. Indeed, the recovery time for muscle oxygenation accurately differentiates severe from moderate claudication,[32,33] and angioplasty increases the hemoglobin oxygen recovery rate after exercise.[34] Although we previously showed that the stop duration between

2 walking bouts limited by usual symptoms is probably an important predictor of forthcoming community-based walking impairment,[10] the present study does not appear to confirm one of our initial hypothesis regarding this aspect. One explanation is the absence of concordance between pain relief and hemodynamic recovery in PAD patients.[35] This lack of concordance could explain that the duration of a stop is less influenced by revascularization than the hemodynamic parameters are. The GPS device used does not allow physiological parameters to be analyzed, but future developments could allow for the recording of physiological signals and a better estimation of the relationship between average-DS_{CW} and hemodynamic recovery.

Study Limitations

The limitations of the present study include the fact that we did not systematically study bypass patency or the results of angioplasty in terms of hemodynamic improvement (e.g., ABI or Doppler measurements) or MWD-on-treadmill, as many patients received their GPS at home at T1 and did not undergo de novo ABI measurement. It is also possible that certain patients in the revascularized group did not improve because their revascularizations failed. We hoped to avoid any additional visits for the routine follow-up of patients and to allow ''at-home'' estimation of walking limitation. These ''at-home'' procedures can also explain the relatively high number of missing scores, specifically for the WIQ and PASE, which are relatively complex questionnaires. Although it is clear that GPS will never replace vascular investigations, we think that it may improve our knowledge of the functional impairments that are associated with PAD.

A second limitation of this study is that we included only PAD patients with classical symptoms of intermittent claudication and for whom self-reported limitation was confirmed during the first GPS test. It would be of interest to evaluate the clinical applicability of and interest in the GPS technique in non-PAD patients (e.g., spinal stenosis, musculoskeletal lesions) or in PAD patients with atypical symptoms. It would also be of interest to analyze whether GPS may help to detect those patients who claim to be asymptomatic or who have stable moderate claudication but in fact progressively decrease walking speed rather than distance. Whether such patients require specific attention is a fascinating issue.

The third limitation is that the ability to perform GPS measurements may depend on the area where the system is used. The present study used a multicenter approach and appears to confirm that when patients are allowed to choose an area consistent with the study requirements, recordings of acceptable quality can be acquired in most cases.

Last, an hour-long stroll may be an unusually long exercise for most PAD patients with claudication. As most elderly patients walk $<$4000 steps per day,[36,37] a 1-hour stroll may not reflect the usual physical activity of most patients. However, we previously showed that walking for 1 hour was considered very difficult in less than one-third of patients;[11] nonetheless, reducing the duration of a stroll might dramatically affect the estimation of highest-MD_{CW} (see Supplemental Digital Content 1, http://links.lww.com/MD/A265).

Conclusion and Clinical Perspective

The major results of the present study can be summarized as follows:

1. In patients who undergo revascularization for arterial claudication, highest-MD_{CW} and average-WS_{CW} are significantly increased. On the contrary average-DS_{CW} changes in revascularized patients do not reach significance compared with reference patients.
2. Among revascularized patients with MCII compared with reference patients, nearly one-third of the patients increased their average-WS_{CW}, but not their highest-MD_{CW}, emphasizing the importance of evaluating speed changes in PAD patients.
3. The correlation between average-WS_{CW} and WIQ-speed changes is weaker than between highest-MD_{CW} and WIQ-distance changes.

Previous studies have demonstrated the accuracy of GPS in measuring community-based walking dimensions such as highest-MD_{CW}, average-WS_{CW} and average-DS_{CW}[10,12,13] in PAD patients. To the best of our knowledge, this is the first prospective multicenter follow-up study using GPS in patients with claudication. Although the present study focused on PAD patients, we assume that the technique could provide new data and interesting information on changes in walking impairment resulting from various medical or surgical treatments. Of major interest is the fact that, at least in PAD, average-WS_{CW} appears essential to account for the changes observed in revascularized patients, beyond the measurement of walking distance alone.

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REFERENCES

1. McDermott MM, Liu K, Greenland P, et al. Functional decline in peripheral arterial disease: associations with the ankle brachial index and leg symptoms. *JAMA*. 2004;292:453–461.
2. McDermott MM, Liu K, Ferrucci L, et al. Decline in functional performance predicts later increased mobility loss and mortality in peripheral arterial disease. *J Am Coll Cardiol*. 2011;57:962–970.
3. McDermott MM, Liu K, Guralnik JM, et al. Measurement of walking endurance and walking velocity with questionnaire: validation of the walking impairment questionnaire in men and women with peripheral arterial disease. *J Vasc Surg*. 1998;28:1072–1081.
4. Hiatt WR, Hirsch AT, Regensteiner JG, et al. Clinical trials for claudication. Assessment of exercise performance, functional status, and clinical end points. Vascular Clinical Trialists. *Circulation*. 1995;92:614–621.
5. Le Faucheur A, Abraham P, Jaquinandi V, et al. Measurement of walking distance and speed in patients with peripheral arterial disease: a novel method using a global positioning system. *Circulation*. 2008;117:897–904.
6. Dormandy JA, Rutherford RB. Management of peripheral arterial disease (PAD). TASC Working Group. TransAtlantic Inter-Society Consensus (TASC). *J Vasc Surg*. 2000;31 (1 Pt 2):S1–S296.

7. Fakhry F, van de Luijtgaarden KM, Bax L, et al. Supervised walking therapy in patients with intermittent claudication. *J Vasc Surg.* 2012;56:1132–1142.
8. Anonymous. Management of peripheral arterial disease (PAD). TransAtlantic Inter-Society Consensus (TASC). *Eur J Vasc Endovasc Surg.* 2000;19(Suppl A)Si-xxviii, S1-250.
9. Nordanstig J, Broeren M, Hensater M, et al. Six-minute walk test closely correlates to ‘‘real-life’’ outdoor walking capacity and quality of life in patients with intermittent claudication. *J Vasc Surg.* 2014;60:404–409.
10. Le Faucheur A, Noury-Desvaux B, Mahe G, et al. Variability and short-term determinants of walking capacity in patients with intermittent claudication. *J Vasc Surg.* 2010;51:886–892.
11. Gernigon M, Le Faucheur A, Noury-Desvaux B, et al. Applicability of global positioning system for the assessment of walking ability in patients with arterial claudication. *J Vasc Surg.* 2014;60:973–981.
12. Tew G, Copeland R, Le Faucheur A, et al. Feasibility and validity of self-reported walking capacity in patients with intermittent claudication. *J Vasc Surg.* 2013;57:1227–1234.
13. Le Faucheur A, Abraham P, Jaquinandi V, et al. Study of human outdoor walking with a low-cost GPS and simple spreadsheet analysis. *Med Sci Sports Exerc.* 2007;39:1570–1578.
14. Abraham P, Noury-Desvaux B, Gernigon M, et al. The inter- and intra-unit variability of a low-cost GPS data logger/receiver to study human outdoor walking in view of health and clinical studies. *PLoS One.* 2012;7:e31338.
15. Copay AG, Subach BR, Glassman SD, et al. Understanding the minimum clinically important difference: a review of concepts and methods. *Spine J.* 2007;7:541–546.
16. Barzilay Y, Noam S, Meir L, et al. Assessing the outcomes of spine surgery using global positioning systems. *Spine (Phila Pa 1976)* 2011;36:E263–E267.
17. Jayaraman A, Deeny S, Eisenberg Y, et al. Global position sensing and step activity as outcome measures of community mobility and social interaction for an individual with a transfemoral amputation due to dysvascular disease. *Phys Ther.* 2014;94:401–410.
18. Murphy TP, Soares GM, Kim HM, et al. Quality of life and exercise performance after aortoiliac stent placement for claudication. *J Vasc Interv Radiol.* 2005;16:947–953quiz 954.
19. Jaquinandi V, Picquet J, Saumet JL, et al. Functional assessment at the buttock level of the effect of aortobifemoral bypass surgery. *Ann Surg.* 2008;247:869–876.
20. Matsumura JS, Yamanouchi D, Goldstein JA, et al. The United States StuDy for EvalUating EndovasculaR TreAtments of Lesions in the Superficial Femoral Artery and Proximal Popliteal By usIng the Protege EverfLex NitInol STent SYstem II (DURABILITY II). *J Vasc Surg.* 2013;58:73–83.
21. Regensteiner JG, Hargarten ME, Rutherford RB, et al. Functional benefits of peripheral vascular bypass surgery for patients with intermittent claudication. *Angiology.* 1993;44:1–10.
22. Nicolai SP, Kruidenier LM, Rouwet EV, et al. The walking impairment questionnaire: an effective tool to assess the effect of treatment in patients with intermittent claudication. *J Vasc Surg.* 2009;50:89–94.
23. McDermott MM, Ohlmiller SM, Liu K, et al. Gait alterations associated with walking impairment in people with peripheral arterial disease with and without intermittent claudication. *J Am Geriatr Soc.* 2001;49:747–754.
24. McCully K, Leiper C, Sanders T, et al. The effects of peripheral vascular disease on gait. *J Gerontol A Biol Sci Med Sci.* 1999;54:B291–294.
25. Gardner AW, Skinner JS, Vaughan NR, et al. Comparison of treadmill walking and stair climbing over a range of exercise intensities in peripheral vascular occlusive disease. *Angiology.* 1993;44:353–360.
26. Degischer S, Labs KH, Aschwanden M, et al. Reproducibility of constant-load treadmill testing with various treadmill protocols and predictability of treadmill test results in patients with intermittent claudication. *J Vasc Surg.* 2002;36:83–88.
27. McDermott MM, Greenland P, Liu K, et al. Sex differences in peripheral arterial disease: leg symptoms and physical functioning. *J Am Geriatr Soc.* 2003;51:222–228.
28. Wilson AM, Sadrzadeh-Rafie AH, Myers J, et al. Low lifetime recreational activity is a risk factor for peripheral arterial disease. *J Vasc Surg.* 2011;54:427–432.
29. McDermott MM, Guralnik JM, Ferrucci L, et al. Asymptomatic peripheral arterial disease is associated with more adverse lower extremity characteristics than intermittent claudication. *Circulation.* 2008;117:2484–2491.
30. McDermott MM, Liu K, Ferrucci L, et al. Greater sedentary hours and slower walking speed outside the home predict faster declines in functioning and adverse calf muscle changes in peripheral arterial disease. *J Am Coll Cardiol.* 2011;57:2356–2364.
31. McDermott MM, Tian L, Liu K, et al. Prognostic value of functional performance for mortality in patients with peripheral artery disease. *J Am Coll Cardiol.* 2008;51:1482–1489.
32. Komiyama T, Shigematsu H, Yasuhara H, et al. Near-infrared spectroscopy grades the severity of intermittent claudication in diabetics more accurately than ankle pressure measurement. *Br J Surg.* 2000;87:459–466.
33. Comerota AJ, Throm RC, Kelly P, et al. Tissue (muscle) oxygen saturation (StO2): a new measure of symptomatic lower-extremity arterial disease. *J Vasc Surg.* 2003;38:724–729.
34. Beckitt TA, Day J, Morgan M, et al. Calf muscle oxygen saturation and the effects of supervised exercise training for intermittent claudication. *J Vasc Surg.* 2012;56:470–475.
35. Gardner AW. Dissipation of claudication pain after walking: implications for endurance training. *Med Sci Sports Exerc.* 1993;25:904–910.
36. Storti KL, Arena VC, Barmada MM, et al. Physical activity levels in American-Indian adults: the Strong Heart Family Study. *Am J Prev Med.* 2009;37:481–487.
37. Bennett GG, Wolin KY, Puleo E, et al. Pedometer-determined physical activity among multiethnic low-income housing residents. *Med Sci Sports Exerc.* 2006;38:768–773.