Eur J Vasc Endovasc Surg (2015) 50, 623—629

Test-retest Reliability of GPS derived Measurements in Patients with Claudication

M. Gernigon [a,b], **A. Fouasson-Chailloux** [a], **C. Colas-Ribas** [a], **B. Noury-Desvaux** [b,c], **A. Le Faucheur** [d,e], **P. Abraham** [a,b,*]

[a] Laboratory for Exercise Investigations, University Hospital, Angers, France
[b] Department of Integrated Neurovascular and Mitochondrial Biology, Angers, France
[c] APCoSS, Institute of Physical Education and Sports Sciences, Les Ponts de Cé, France
[d] Movement, Sport and Health Laboratory, University of Rennes, Rennes, France
[e] Ecole normale supérieure de Rennes, Department of Sports science and physical education, Bruz, France

WHAT THIS PAPER ADDS

GPS can monitor community walking in PAD patients with claudication. Despite the apparent variability of GPS derived parameters observed within a single stroll, the greatest distance walked between stops and the mean walking speed are reliable parameters in test-retest recordings. GPS appears to be a new easy to use and low cost way of evaluating walking ability in PAD patients. It could be useful to follow the walking ability of PAD patients without laboratory referral. It could be of specific interest in private practice, in epidemiological studies, or for patients coming from isolated geographic areas.

Objective: In patients with peripheral artery disease (PAD), the different distances between stops and the stop durations recorded with Global Positioning System (GPS) during a 1 hour stroll in the community are highly variable. Nevertheless, the reliability of the greatest community walk distance (greatest distance), the average of walking speeds (average speed) and the durations of stops (average stop durations) have not been studied.
Design: Seventeen PAD patients performed two series of evaluations (T1 and T2) within a 1 month period.
Methods: Each series included: a 1 hour stroll in the community with the calculation of the walking impairment questionnaire (WIQ) scores, the measurement of maximal walking distance on a treadmill (MWD on treadmill) and a 1 hour stroll in the community with GPS. The Garmin GPS-60 (Garmin Ltd, Olathe, Kan) receiver was used for all patients. Test-retest reliability of MWD on treadmill, WIQ, and GPS parameters were assessed with intraclass coefficient of correlation (ICC).
Results: ICCs are almost perfect between T1 and T2 for greatest distance (ICC = 0.911), average speed (ICC = 0.905), and MWD on treadmill (ICC = 0.992), and substantial for the average WIQ (ICC = 0.794). Correlation of average stop durations was considered substantial (ICC = 0.691).
Conclusions: Despite the previously reported "within stroll" variability of walking bouts for distances, speeds, and stop durations, GPS derived greatest distance and average speed are reliable in PAD patients in test-retest experiments. The GPS appears to be a new tool to assess walking limitation and allows objective clinical investigation.

Article history: Received 9 January 2015, Accepted 8 July 2015, Available online 28 August 2015
Keywords: Peripheral vascular disease, Claudication, Diagnosis, Exercise, Test, Global positioning system

INTRODUCTION

Lower extremity peripheral artery disease (PAD) is a chronic condition, for which the common initial symptom is characterised by intermittent claudication. Claudication is defined as a pain or discomfort that limits walking ability, forcing the patient to slow down or stop and disappearing within 10 minutes of stopping, then allowing further walking.[1–4] PAD is associated with a decrease in maximal walking distance (MWD: the absolute maximum distance walked before limb discomfort or pain forces the patient to stop) and a decrease in walking speed. Reduced performance is related to an increased risk of mortality.[5] There are various tools available to evaluate the characteristics associated with walking limitation in patients with PAD. Among available tools are questionnaires such as the walking impairment questionnaire (WIQ)[6–8] and treadmill tests.[3,9] Each of these tools may evaluate the walking limitation, but do not provide objective evaluation of walking in the community ($_{CW}$) such as the walking speed or the duration

* Corresponding author. Laboratory for Exercise Investigations, University Hospital, Angers F-49933, France.
E-mail address: piabraham@chu-angers.fr (P. Abraham).
1078-5884/© 2015 European Society for Vascular Surgery. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ejvs.2015.07.009

of stops between walking bouts. Global Positioning System (GPS) has been proposed as an original tool to measure walking ability in PAD in the community.[10–12] GPS can be used to simultaneously evaluate distance, speed, and the duration of stops, as well as record various walking bouts in the same patient, provided that the recorded walking period is long enough (45–60 min) to allow multiple walking bouts within a single stroll. Further, with GPS, no calibration (e.g. pedometers) or integration (e.g. accelerometers) is needed to retrieve distance, speed, or time. Previously, it was shown that during a GPS recorded prescribed 1 hour stroll in the community, the various walking speeds between stops (WS_{CW}) for the different walking bouts were relatively homogeneous, whereas large variability was found in stop durations between walking bouts (DS_{CW}).[13] Further, in routine clinical practice patients are expected to have "a" MWD, used as an indicator. However, previously a large variability was observed in the different measured distances between two symptom limited stops (MD_{CW}) during a 1 hour stroll.[13] Despite this "within stroll" variability of MD_{CW}, the greatest of these various observed MD_{CW} values (greatest distance), correlates with the self reported MWD[11] and with the maximum distance performed on treadmill (MWD on treadmill).[10]

An essential step for the potential use of GPS in PAD patients is to determine the reliability of GPS derived parameters of walking ability. Ultimately, GPS appears to be a new tool to assess the walking limitation and could become another useful way to objectively assess walking of PAD patients. The present study focused on the greatest distance, the average of walking speeds (average speed), and the average of stop durations (average stop durations). The aim of the present study was to estimate the test-retest reliability of these GPS-derived parameters in PAD patients under community walking conditions. It was hypothesised that, despite the large variability observed for MD_{CW} and DS_{CW} within a 1 hour stroll, the greatest distance, the average speed and the average stop durations would be reliable parameters in test-retest recordings.

MATERIALS AND METHODS

Patients

A prospective study was conducted to include 20 patients with intermittent claudication. Because only one GPS was available for the study and issues appeared with its sampling rate, it took time to identify the issues, contact the company, and replace the GPS, thus the inclusion period was from October 2007 to March 2010. Inclusion criteria included: age $>$ 18 years old; stage II vascular type intermittent claudication (Leriche and Fontaine classification) defined as a fatigue, discomfort or pain occurring in the calf, thigh, or buttock during exercise that resolved within 10 minutes of rest; an ankle brachial systolic pressures index (ABI) $<$ 0.90,[14] or an ABI $<$ 0.95 with an exercise transcutaneous oxygen pressure ($tcpO_2$) decrease from rest of oxygen pressure (DROP) index < -15 mmHg[15,16]; ability to attend the second series of evaluations; clinical stability of the severity of PAD in the 3 months preceding inclusion. Exclusions included patients with any ongoing symptomatic disease that limited exercise other than PAD (e.g. lumbar spine syndrome, limiting exertional dyspnoea, or symptomatic arthritis), and patients at risk from exercise tests (myocardial infarction in the last 6 months, uncontrolled angina pectoris, sustained cardiac arrhythmias, abdominal aortic aneurysm $>$ 40 mm). Moreover, both resting ABI[3,4] and exercise DROP index[15,16] were used to make the diagnosis of vascular claudication in isolated proximal claudication where ABI can remain within normal limits.[17–19]

The procedures used in this study were approved by the CPP-Ouest II ethics committee and performed according to the international ethics standards and the Declaration of Helsinki. The study was promoted and monitored by the University Hospital of Angers (France) and was registered in the American National Institutes of Health database under reference n° NCT00485147 (www.ClinicalTrials.gov). All patients provided written informed consent to participate in the study. After enrolment, two series of evaluations were scheduled on two different days. Test 1 (T1) and test 2 (T2) included laboratory and outdoor (GPS) evaluations of walking ability. T2 was scheduled, at least 1 day and within 1 month of T1. Exclusion criteria included any change in the medical treatment, any kind of surgical revascularisation between T1 and T2, and missing GPS data in T1 or T2.

Laboratory investigations

After enrolment, height (cm), body mass (kg), ABI, comorbid conditions, claudication history, cardiovascular risk factors, medical or surgical history, and ongoing medications were obtained from medical files as well as medical history and physical examination. At both T1 and T2, laboratory evaluations first included the completion of the WIQ[6] and then the measurement of MWD on treadmill (3.2 km/h; 10% grade; maximised to 20 minutes).[15,18] The patients were blinded to the results of each evaluation. As with T1, the laboratory evaluations for T2 were performed on the same day as the second GPS 1 hour stroll.

GPS investigations

The outdoor stroll was always performed on the same day just after the laboratory investigations. The Garmin GPS-60 (Garmin Ltd, Olathe, Kan) was used on all patients. For technical reasons, from patient 5, another type of GPS was used simultaneously. Data for this second device are reported as additional "online only" data. GPS were worn in a backpack and the antenna was positioned on the right shoulder. GPS devices were both started and stopped in the laboratory before and after the stroll. Following a standard procedure,[13] patients were asked to perform a 1 hour stroll (including stop durations) alone. The stroll was organised in a pre-defined public park near the hospital. This park is free from cars or any kind of motorised vehicles, is relatively free of compact trees, and contains a large variety of flat pedestrian paths. As previously published,[10] patients were asked to walk at their usual pace and only stop at maximal pain. The T2 stroll was performed in the same park, but not necessarily using the same pedestrian paths.

Recorded data were downloaded to a personal computer and analysed according to a previously published procedure.[10,13,20] For each recording, the methodology was used as previously described, and all MD_{CW}, WS_{CW}, and DS_{CW} were calculated.[10,13,20] From these parameters, the greatest distance, average speed, and average stop durations were extracted. The last MD_{CW} and corresponding WS_{CW} were not used to calculate the greatest distance and average speed except if the last MD_{CW} was higher than any previously measured MD_{CW}.[13]

Weather conditions

Wind velocity, rain, and temperature at the time of each recording were obtained from the local weather station.

Statistical analysis

The minimum number of patients needed to obtain a statistical power of 90% ($p < .05$) for a confident interval of 95% was 17. According to normal distribution, data are expressed as mean ± SD or as median with (25th to 75th percentiles), where appropriate. For each laboratory and community evaluation, the Bland-Altman plots[21] and the intraclass correlation coefficient (ICC) with 95% confidence interval were performed to evaluate the test-retest reliability. ICC values were ranked as poor (0.00—0.20), fair (0.21—0.40), moderate (0.41—0.60), substantial (0.61—0.80), or almost perfect (0.81—1.00).[22] The student paired *t* test (or Wilcoxon as appropriate) were performed to compare T1 and T2 results. Statistical analyses were performed with SPSS (V17.0.0 SPSS Inc., 2008). For all statistical tests, a two tailed probability level of $p < .05$ was used to indicate statistical significance.

RESULTS

Three of the included patients had to be excluded (highly noise non-interpretable signal or patient refusal to perform the second series of laboratory evaluations). Characteristics of the 17 patients are reported in Tables 1 and 2. Note that data are missing for some questionnaires because of difficulties and non-completion by the patients (Table 2).

Fig. 1 shows a typical example of the recordings observed for the same patient during the two GPS strolls. There were no significant differences between the walks for temperature ($p = .65$), wind ($p = .82$) or rain ($p = .32$). As shown in Fig. 1, the footpaths used were different. Fig. 1 also clearly illustrates the wide variability of MD_{CW} observed for each walking bout within each stroll, ranging from a minimum MD_{CW} of 90 m to a greatest distance of 487 m at T1 and from a minimum MD_{CW} of 228 m to a greatest distance of 550 m at T2. Also of interest is the fact that the speed (that can be visually estimated from the slope of each walking bout) is relatively stable between the different bouts and between T1 and T2.

The median delay between T1 and T2 was 7 [6; 14] days. Fig. 2 is the representation of reliability according to the Bland-Altman analysis, and Tables 3 and 4 present the results of reliability analysis for both laboratory and GPS evaluations. As shown in Table 3, laboratory measurements showed almost perfect reliability for the MWD on treadmill. From questionnaire results, WIQ_{avg} score, WIQ distance, and WIQ speed sub-scores are substantial (i.e. 0.61 < ICC<0.80), compared with the WIQ stairs climbing sub-score which is almost perfect (0.81 < ICC). For GPS, an almost perfect reliability was found for studied parameters between T1 and T2 except for the average stop durations which is substantial (Table 4 and Fig. 2). The correlation for GPS parameters between T1 and T2 is high except for the duration of stops.

Table 1. Patient characteristics.

Clinical characteristics	$n = 17$
Age, years	64 ± 7
Weight, kg	79 ± 15
Height, cm	166 ± 7
Body mass index, kg/m^2	28.5 ± 4.2
Male sex, no. (%)	15 (88%)
Disease history, years	3.5 [1.4;8.5]
Ankle brachial index	0.75 [0.67;0.82]
$TcPO_2$ DROP min, mmHg	−32 [−45;−28]
Comorbidities, (history of), no. (%)	
Smoker (current or former)	16 (94%)
Coronary disease	4 (24%)
Sleep apnoea	1 (6%)
Hypercholesterolaemia	8 (47%)
Diabetes	5 (29%)
History of vascular surgery (lower limbs)	5 (29%)
Current medications, no. (%)	
Fibrates or statins	13 (76%)
Anti-diabetic	5 (29%)
Anti-hypertensive	12 (71%)
Beta blocker	8 (47%)
Antiplatelet	17 (100%)

Results are presented as mean ± SD, median [25th;75th], or number of observation (%).

DISCUSSION

A community based approach is necessary to provide access to healthcare for patients who cannot get to a hospital and to contain health insurance costs. Despite the variability of the different within stroll MD_{CW}, the reliability of greatest distance and average speed is good. Contrary to the study hypothesis, average stop durations was not as reliable as the other two parameters.

Multiple studies have addressed the question of MWD on treadmill reliability (see the meta-regression analysis by Nicolaï et al. for an exhaustive listing of these studies).[23] The interpretation of reliability depends on the statistical parameter used.[24] For constant load protocols at 3.2 km/h with a 10% (or 12%) gradient, available studies reported ICCs ranging from 0.72 to 0.93.[23] However, even if treadmill evaluations are considered to be the gold standard method for measuring walking impairment in PAD, they are time consuming, expensive, and not readily accessible to all physicians. Furthermore, one limitation is that the treadmill does not satisfactorily reproduce the spontaneous

Table 2. Patient characteristics for each walking parameter.

	N	T1	T2
WIQ[a] distance subscore (%)	16	36.0 [12.1; 62.7]	31.0 [17.1; 69.1]
WIQ[a] speed subscore (%)		25.0 [14.1; 36.1]	28.3 [20.9; 41.0]
WIQ[a] stairs subscore (%)		33.3 [16.6; 66.6]	44.8 [27.1; 66.6]
WIQ[a] mean		36.8 [22.5; 46.6]	40.9 [21.2; 57.0]
Self reported MWD [a] [b] (m)	17	250 [100; 500]	500 [200; 700]
MWD on treadmill[c] (m)	17	109 [92; 138]	119 [82, 178]
Total distance$_{CW}$ (m)	17	3139 [2267; 3700]	3125 [2185; 3643]
Total time duration$_{CW}$ (min)		61.23 [60.07; 70.87]	65.56 [59.00; 75.43]
Greatest distance[d] (m)		537 [351; 1620]	804 [324; 1532]
Average speed[e] (km.h^{-1})		3.42 [3.17; 3.92]	3.42 [2.95; 3.83]
Average stop durations[f] (min)		1.30 [0.93; 2.58]	1.73 [1.25; 2.34]

Results are presented as median [25th:75th].
[a] WIQ: "walking impairment questionnaire".
[b] Self reported MWD: "maximum walking distance self reported".
[c] MWD on treadmill: "maximum walking distance performed on the treadmill".
[d] Greatest distance: "greatest measured distance between two stops during community walking".
[e] Average speed: "average walking speed during community walking".
[f] Average stop durations: "average stop durations during community walking".

community walk of PAD patients and is rarely used to provide parameters such as spontaneous walking speed and stop durations. This could be useful in vascular patients but also in many other diseases (e.g. pulmonary or cardiac disease, lumbar spine stenosis, etc.).

Among methodological approaches, a way of evaluating walking speed is estimation through questionnaires. Substantial to almost perfect ICCs were found for WIQ sub-scores. The ICC reported for WIQ sub-scores and scores are in the range of those reported in other studies.[26–28]

GPS appears to be an interesting tool for estimating walking parameters in community conditions in diseased patients and healthy subjects.[10,13,20,29] Of interest the reliability of test-retest greatest distance is in the high range of those usually observed in test-retest recording of MWD on treadmill in PAD patients.[23,30–33] The almost perfect reliability of greatest distance and average speed observed here is an essential methodological prerequisite for long-term follow up studies in PAD patients. GPS allows new investigations of walking limitation parameters of PAD

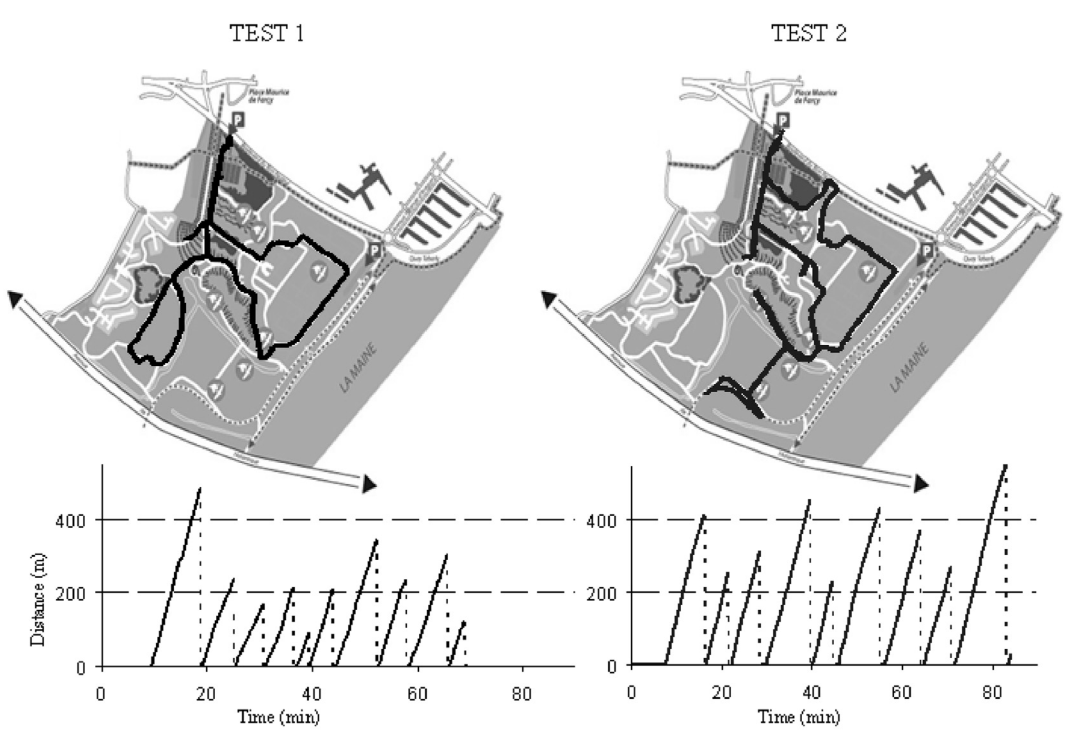
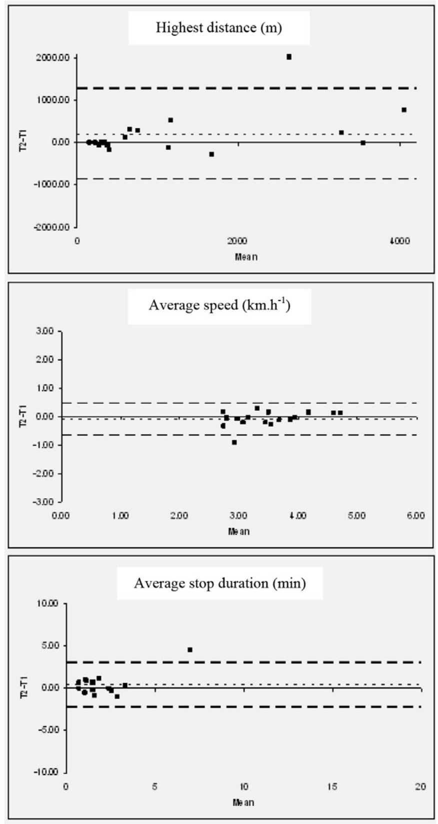


Figure 1. Example of the recordings observed during the two strolls (Test 1 and Test 2) in the same patient in the "Parc Balzac". Both strolls (black lines) were started at the parking lot, north of the park. The graphs under each image represent cumulated distance between each stop.



Highest distance: "highest measured distance between two stops during community walking"; **Average speed:** "average walking speed during community walking"; **Average stop duration:** "average stop duration during community walking".

Figure 2. Test-retest reliability with Bland-Altman representation for the different GPS derived parameters between the two strolls.

patients such as speed and time recovery. These new parameters more precisely described the walking pattern and may show the benefit of treatment or surgery.

Potential advantages of GPS include the price of the test and time saved. The GPS receiver can be used for multiple patients. In the present study, the patient came back to the laboratory to give the GPS back for analysis. More recently the GPS is returned in a pre-stamped envelope using regular surface mail system for less than 8 $.[25] The time required to manually analyse a GPS recording is 10–20 minutes but will decrease with expertise and automation of the analyses.

Table 3. Results at T1 and T2 of laboratory investigations.

	N	ICC [95% CI] (*p*)	Wilcoxon test
$WIQ_{distance}$[a]	16	0.616 [0.203; 0.845] (.003)	0.551
WIQ_{speed}		0.749 [0.429; 0.904] (<.001)	0.551
WIQ_{stairs}		0.902 [0.749; 0.964] (<.001)	0.153
WIQ_{mean}		0.794 [0.515; 0.922] (<.001)	0.776
Self reported MWD[b] (m)	17	0.473 [0.018; 0.769] (.021)	0.038
MWD on treadmill[c] (m)	17	0.992 [0.978; 0.997] (<.001)	0.551

Results are presented as intraclass coefficient of correlation (ICC), and *p* for the Wilcoxon test.
[a] WIQ: "walking impairment questionnaire".
[b] Self reported MWD: "maximum walking distance self reported".
[c] MWD on treadmill: "maximum walking distance performed during the treadmill test".

Table 4. Walking parameter results for the patients that fully completed both series of tests.

	N	ICC [95% CI] (*p*)	Wilcoxon test
Greatest distance[a] (m)	17	0.911 [0.776; 0.966] (<.001)	0.306
Average speed[b] ($km.h^{-1}$)	17	0.905 [0.762; 0.964] (<.001)	0.420
Average stop durations[c] (min)	15	0.691 [0.308; 0.883] (.001)	0.330
Number of stops	17	0.899 [0.750; 0.962] (<.001)	0.193
Total $distance_{CW}$ (m)	17	0.947 [0.863; 0.980] (<.001)	0.190

Results are presented as intraclass coefficient of correlation (ICC), the Pearson coefficient with 95% confidence interval [95% CI] and the student *t* test.
[a] Greatest distance: "greatest measured distance between two stops during community walking".
[b] Average speed: "average walking speed during community walking".
[c] Average stop durations: "average stop durations during community walking".

Table 5. List of abbreviations.

Abbreviations	Meanings and definitions
DS_{CW}	Stop durations between walking bouts during community walking
GPS	Global Positioning System
ICC	Intraclass coefficient of correlation
MWD	Maximal walking distance: the absolute maximum distance walked before limb discomfort or pain forces the patient to stop
MD_{CW}	Measured distance in community walking between two symptom-limited stops. One patient may have multiple measured distances in a 1 hour recording
PAD	Peripheral artery disease
WIQ	Walking impairment questionnaire
WS_{CW}	Walking speed during community walking: mean walking speed between two stops during community walking

Study limitations

First, in addition to a non-formal standardisation between T1 and T2 (i.e. within a month and the median period was 2 weeks), the route that the patients took and the environmental conditions of temperature, wind speed/directions, etc may have changed between T1 and T2 and could potentially have an impact on reliability measures when considering the community-based approach. Second, a learning effect between T1 and T2 cannot be ruled out. This could explain the slightly (although non-significant) improved ability at T2. Third, previous reports have suggested a gender difference in the walking ability of PAD patients.[34] Unfortunately, the small sample size in this study does not allow a gender specific analysis. Fourth, a 1 hour stroll may appear an unusually long exercise for most PAD patients leading to fatigue as a cause of walking impairment. This is true but on the one hand, it has previously been shown that cumulated time (and thus fatigue) was assumed to be responsible for walking impairment in less than 15% of patients during 1 hour strolls.[13] On the other hand, each patient was their own control and it is unlikely that fatigue differed between T1 and T2. Nevertheless, the authors agree that studies are needed to analyse the influence of shortening the duration of the stroll on GPS derived parameters. Fifth, all the GPS strolls were performed in a single carefully selected park. Applicability of the technique in non-flat areas, dense environment, and non-pre-defined places remains to be studied. A recent study provides answers to some of these issues.[25] Coupling GPS data with other activity monitors (accelerometers, gyroscopes, etc.) might facilitate the use of the technique in obstructed environments and enable monitoring of both indoor and outdoor activities. Sixth, there was no evidence or proof that all stops were related to pain. This is a pitfall of the technique as used here. Nevertheless, it is expected that in future GPS devices may be able to record physiological parameters (e.g. heart rate, near infrared spectroscopy, temperature, etc.). Once again, the problem will be to keep the price of these multi-parameter devices low and keep the analysis of recorded data simple enough for routine use. Last, if the aim is to record routine community walks or to perform prolonged recordings for several hours or days, the ethical issues related to the use of new communication technologies and to the monitoring of daily living should not be neglected.

CONCLUSION

The present study suggests that GPS technology offers new perspectives in individual evaluation of walking ability, at least in PAD. GPS derived greatest distance and average speed are reliable measures of walking ability in PAD patients during test-retest 1 hour stroll recordings, despite the previously reported “within stroll” variability of the different recorded distances and stop durations. GPS allows the investigation of walking limitation of PAD patients in conditions as close as possible to a usual walk. A cohort long-term follow up study is needed to analyse the effect of treatments over greatest distance, average speed, or walking pattern improvements in PAD patients with intermittent claudication.

Please refer to Table 5 for abbreviations list.

CONFLICT OF INTEREST

None.

FUNDING

This study was supported by a grant from the University Hospital of Angers with the support of the Société Française de Médecine Vasculaire. The grant number was CHU_PROMOTEUR_2005_04.

ACKNOWLEDGEMENT

The authors thank J-F Hamel for technical help.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ejvs.2015.07.009

REFERENCES

1 Rose GA. The diagnosis of ischaemic heart pain and intermittent claudication in field surveys. *Bull World Health Organ* 1962;**27**:645—58.

2 Hirsch AT, Haskal ZJ, Hertzer NR, Bakal CW, Creager MA, Halperin JL, et al. ACC/AHA 2005 Practice Guidelines for the management of patients with peripheral arterial disease (lower extremity, renal, mesenteric, and abdominal aortic): a collaborative report from the American Association for Vascular Surgery/Society for Vascular Surgery, Society for Cardiovascular Angiography and Interventions, Society for Vascular Medicine and Biology, Society of Interventional Radiology, and the ACC/AHA Task Force on Practice Guidelines (Writing Committee to Develop Guidelines for the Management of Patients With Peripheral Arterial Disease): endorsed by the American Association of Cardiovascular and Pulmonary Rehabilitation; National Heart, Lung, and Blood Institute; Society for Vascular Nursing; TransAtlantic Inter-Society Consensus; and Vascular Disease Foundation. *Circulation* 2006;**113**:e463—654.

3 Dormandy JA, Rutherford RB. Management of peripheral arterial disease (PAD). TASC Working Group. TransAtlantic Inter-Society Consensus (TASC). *J Vasc Surg* 2000;**31**:S1—296.

4 Creager MA, Belkin M, Bluth EI, Casey Jr DE, Chaturvedi S, Dake MD, et al. 2012 ACCF/AHA/ACR/SCAI/SIR/STS/SVM/SVN/SVS Key data elements and definitions for peripheral atherosclerotic vascular disease: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Clinical Data Standards (Writing Committee to develop Clinical Data Standards for peripheral atherosclerotic vascular disease). *J Am Coll Cardiol* 2012;**59**:294—357.

5 McDermott MM, Tian L, Liu K, Guralnik JM, Ferrucci L, Tan J, et al. Prognostic value of functional performance for mortality in patients with peripheral artery disease. *J Am Coll Cardiol* 2008;**51**:1482—9.

6 Hiatt WR, Hirsch AT, Regensteiner JG, Brass EP. Clinical trials for claudication. Assessment of exercise performance, functional status, and clinical end points. Vascular Clinical Trialists. *Circulation* 1995;**92**:614—21.

7 Mahe G, Ouedraogo N, Vasseur M, Faligant C, Saidi K, Leftheriotis G, et al. Limitations of self reported estimates of functional capacity using the walking impairment questionnaire. *Eur J Vasc Endovasc Surg* 2011;**41**:104—9.

8 Regensteiner JG, Ware Jr JE, McCarthy WJ, Zhang P, Forbes WP, Heckman J, et al. Effect of cilostazol on treadmill walking, community-based walking ability, and health related quality of life in patients with intermittent claudication due to peripheral arterial disease: meta-analysis of six randomized controlled trials. *J Am Geriatr Soc* 2002;**50**:1939—46.

9 Duprez D, de Backer T, de Buyzere M, Clement DL. Estimation of walking distance in intermittent claudication: need for standardization. *Eur Heart J* 1999;**20**:641—4.

10 Le Faucheur A, Abraham P, Jaquinandi V, Bouye P, Saumet JL, Noury-Desvaux B. 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.

11 Tew G, Copeland R, Le Faucheur A, Gernigon M, Nawaz S, Abraham P. Feasibility and validity of self reported walking capacity in patients with intermittent claudication. *J Vasc Surg* 2013;**57**:1227—34.

12 Nordanstig J, Wann-Hansson C, Karlsson J, Lundstrom M, Pettersson M, Morgan MB. Vascular quality of life questionnaire-6 facilitates health related quality of life assessment in peripheral arterial disease. *J Vasc Surg* 2014;**59**:700—7.

13 Le Faucheur A, Noury-Desvaux B, Mahe G, Sauvaget T, Saumet JL, Leftheriotis G, et al. Variability and short-term determinants of walking capacity in patients with intermittent claudication. *J Vasc Surg* 2010;**51**:886—92.

14 Norgren L, Hiatt WR, Dormandy JA, Nehler MR, Harris KA, Fowkes FG, et al. Inter-Society Consensus for the management of peripheral arterial disease (TASC II). *Eur J Vasc Endovasc Surg* 2007;**33**(Suppl 1):S1—75.

15 Abraham P, Picquet J, Vielle B, Sigaudo-Roussel D, Paisant-Thouveny F, Enon B, et al. Transcutaneous oxygen pressure measurements on the buttocks during exercise to detect proximal arterial ischemia: comparison with arteriography. *Circulation* 2003;**107**:1896—900.

16 Abraham P, Picquet J, Bouye P, L'Hoste P, Enon B, Vielle B, et al. Transcutaneous oxygen pressure measurements (tcpO2) at ankle during exercise in arterial claudication. *Int Angiol* 2005;**24**:80—8.

17 Ouedraogo N, Barbeau C, Legrand M, Marchand J, Leftheriotis G, Abraham P. "Routine" arterial echo-doppler is not sufficient to exclude an arterial origin of exercise-induced proximal lower limb pain. *Int J Cardiol* 2013;**167**:1053—4.

18 Jaquinandi V, Picquet J, Bouye P, Saumet JL, Leftheriotis G, Abraham P. High prevalence of proximal claudication among patients with patent aortobifemoral bypasses. *J Vasc Surg* 2007;**45**:312—8.

19 Picquet J, Jacquinandi V, Saumet JL, Leftheriotis G, Enon B, Abraham P. Systematic diagnostic approach to proximal-without-distal claudication in a vascular population. *Eur J Int Med* 2005;**16**:575—9.

20 Le Faucheur A, Abraham P, Jaquinandi V, Bouye P, Saumet JL, Noury-Desvaux B. Study of human outdoor walking with a low-cost GPS and simple spreadsheet analysis. *Med Sci Sports Exerc* 2007;**39**:1570—8.

21 Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;**8**:307—10.

22 Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;**33**:159—74.

23 Nicolai SP, Viechtbauer W, Kruidenier LM, Candel MJ, Prins MH, Teijink JA. Reliability of treadmill testing in peripheral arterial disease: a meta-regression analysis. *J Vasc Surg* 2009;**50**:322—9.

24 Gernigon M, Le Faucheur A, Laneelle D, Noury-Desvaux B, Mahe G, Abraham P. Reliability of GPS measurements to assess walking limitation in patients with intermittent claudication. *Fundam Clin Pharmacol* 2014;**28**:10.

25 Gernigon M, Le Faucheur A, Noury-Desvaux B, Mahe G, Abraham P. Applicability of global positioning system for the assessment of walking ability in patients with arterial claudication. *J Vasc Surg* 2014;**60**:973—81.

26 Coyne KS, Margolis MK, Gilchrist KA, Grandy SP, Hiatt WR, Ratchford A, et al. Evaluating effects of method of administration on Walking Impairment Questionnaire. *J Vasc Surg* 2003;**38**:296—304.

27 Long J, Modrall JG, Parker BJ, Swann A, Welborn 3rd MB, Anthony T. Correlation between ankle brachial index, symptoms, and health related quality of life in patients with peripheral vascular disease. *J Vasc Surg* 2004;**39**:723—7.

28 Verspaget M, Nicolai SP, Kruidenier LM, Welten RJ, Prins MH, Teijink JA. Validation of the Dutch version of the Walking Impairment Questionnaire. *Eur J Vasc Endovasc Surg* 2009;**37**:56—61.

29 Perrin O, Terrier P, Ladetto Q, Merminod B, Schutz Y. Improvement of walking speed prediction by accelerometry and altimetry, validated by satellite positioning. *Med Biol Eng Comput* 2000;**38**:164—8.

30 Zwierska I, Nawaz S, Walker RD, Wood RF, Pockley AG, Saxton JM. Treadmill versus shuttle walk tests of walking ability in intermittent claudication. *Med Sci Sports Exerc* 2004;**36**:1835—40.

31 Kirby RL, Marlow RW. Reliability of walking endurance with an incremental treadmill test. *Angiology* 1987;**38**:524—9.

32 Montgomery PS, Gardner AW. The clinical utility of a six-minute walk test in peripheral arterial occlusive disease patients. *J Am Geriatr Soc* 1998;**46**:706—11.

33 Falkensammer J, Gasteiger S, Polaschek B, Gruber I, Frech A, Fraedrich G, et al. Reliability of constant-load treadmill testing in patients with intermittent claudication. *Int Angiol* 2012;**31**:150—5.

34 McDermott MM, Greenland P, Liu K, Criqui MH, Guralnik JM, Celic L, et al. Sex differences in peripheral arterial disease: leg symptoms and physical functioning. *J Am Geriatr Soc* 2003;**51**:222—8.