Technical note

Validity and test-retest reliability of the Stride Analyzer in people with knee osteoarthritis

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ABSTRACT

Introduction: Subjects with knee osteoarthritis walk differently compared to healthy subjects. Managing these gait alterations has been proven effective for reducing pain and increasing function. The Stride Analyzer is a low cost gait analysis tool but its clinimetric properties have not been investigated yet in subjects with symptomatic knee osteoarthritis. The aim of this study was to investigate the reliability and validity of the SA compared with the Gold standard (Vicon) in persons with knee OA.
Methods: Fifteen subjects with symptomatic knee osteoarthritis were instructed to walk at a self-selected speed in a gait laboratory. Temporospatial (TS) gait parameters were recorded simultaneously by the Stride Analyzer and by a 16-camera-infrared optoelectronic motion capturing system (Vicon). Validity and test-retest reliability of the Stride Analyzer were examined by Bland-Altman plots, intra-class correlation coefficients (ICC) and the standard error of measurement (SEM).
Results: Test-retest analyses showed good agreement for all TS parameters with ICC values ranging from 0.805 (single limb support right) to 0.949 (velocity) and SEM% values ranging from 0.78% (stance phase right (% of gait cycle)) to 4.52% (double limb support right (% of gait cycle)). Good agreement between Stride Analyzer and Vicon was found for the following TS parameters: velocity ($z = 1.01$), cadence ($z = -0.85$), stride length ($z = 1.63$) and gait cycle ($z = 0.86$). All other gait parameters showed lower ICC values (<0.689).
Interpretation: Our results suggest that the Stride Analyzer can be used in the clinical field to perform gait analysis in subjects with symptomatic knee osteoarthritis.

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1. Introduction

Since the gold standard for gait analyses (i.e. infrared optoelectronic motion capturing system) is an expensive and bulky instrument which requires patients to move to specialized facilities, a portable and less expensive measurement tool may be more appropriate in clinical settings [1]. The Stride Analyzer (SA) is a cheap and portable gait analysis instrument that measures TS parameters and provides easy-to-use graphics. A high test-retest reliability has been shown in healthy and neurological populations but not yet in knee OA patients [2,3].

Knee osteoarthritis (OA) patients and healthy controls show important differences in temporospatial (TS) gait parameters [4]. In addition, stride length and cadence have proven to be two crucial parameters in classifying knee OA severity [5]. Moreover, gait retraining programs have been shown to be helpful in reducing knee OA symptoms [6].

Therefore, the aim of this study is to investigate the reliability and validity of the SA compared with the Gold standard (Vicon) in persons with knee OA.

2. Methods

Measurements were conducted at the Center of Movement analysis in the Rehabilitation hospital of Inkendaal (Vlezenbeek, Belgium) with ethical approval given by the Medical Ethics

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Table 1
Group means of temporospatial gait parameters.

Gait parameters	Stride Analyzer 1 (N = 14)	Stride Analyzer 2 (N = 15)	Vicon (N = 15)
Velocity (m min^{-1})	87.65 (11.01)	90.45 (10.86)	86.78 (10.66)
Cadence (steps min^{-1})	115.98 (6.01)	118.33 (6.1)	119.99 (6.54)
Stride Length (m)	1.51 (0.18)	1.53 (0.2)	1.45 (0.17)
Gait cycle (s)	1.04 (0.05)	1.02 (0.05)	1 (0.05)
Single Limb Support Right (s)	0.38 (0.03)	0.37 (0.02)	0.39 (0.02)
Single Limb Support Left (s)	0.39 (0.03)	0.38 (0.02)	0.39 (0.02)
Single Limb Support Right (%GC)	36.5 (1.52)	36.45 (1.77)	39.05 (1.7)
Single Limb Support Left (%GC)	37.47 (1.3)	37.19 (1.85)	39.06 (1.76)
Swing Phase Right (%GC)	37.47 (1.26)	37.2 (1.85)	39 (1.69)
Swing Phase Left (%GC)	36.5 (1.57)	36.43 (1.76)	39.04 (1.67)
Stance Phase Right (%GC)	62.53 (1.26)	62.8 (1.85)	61 (1.69)
Stance Phase Left (%GC)	63.5 (1.56)	63.56 (1.75)	60.96 (1.67)
Double Limb Support Right (%GC)	25.73 (2.55)	26.12 (3.12)	22.08 (3.17)
Double Limb Support Left (%GC)	25.91 (2.46)	26.25 (3.14)	22.23 (2.86)

Values represent means and standard deviations (m: meter; min: minute; s: seconds; %GC: percentage of gait cycle).

Committees of the University of Brussels and the Rehabilitation hospital of Inkendaal (B.U.N. 143201422593). Participants gave written consent.

2.1. Subjects

Community-dwelling subjects meeting the criteria of the American College of Rheumatology classification for knee OA were recruited (age: 65.0 ± 8.5 years; body mass: 78.0 ± 15.8 kg; height: 1.69 ± 9.7 m; BMI: 27 ± 4.1 kg m^{-2}) [7].

2.2. Outcomes

After a habituation period of 5 trials, the following TS parameters were analyzed: velocity, cadence, stride length, gait cycle (GC), single limb support, single limb support (% of gait cycle

(%GC)), swing phase (%GC), stance phase (% GC), double limb support and double limb support (%GC) (see Appendix A in Supplementary material for definitions of these parameters).

2.3. Materials

The SA 5.10 (B&L Engineering, Santa Ana, CA, USA) is a portable gait analysis tool with a sample rate of 500 Hz consisting of two foot insoles that are attached to a recorder on the patient's waist. Infrared light sources, mounted on the wall, trigger the start and end of data collection.

A 16-camera infrared optoelectronic video-based motion analysis system with a sample rate of 100 Hz (Vicon MXT40-S, Vicon Motion Systems, Oxford, UK) was also used. Three reflecting markers were placed on the shoes near the second metatarsal heads, heels and lateral malleoli of both feet [8]. The marker

Table 2
Reproducibility of the measurement of gait parameters by the Stride Analyzer and Vicon.

Gait parameters	Test Retest Stride Analyzer						Between Stride Analyzer & Vicon							
	Bias 95%CI	ICC (2.1) 95%CI	SEM	SEM %	LoA	SDC	Bias 95%CI	ICC (3.1) 95%CI	SEM	SEM %	LoA	Ratio	Z
Velocity (m min^{-1})	−3.91 [−5.87, −1.95]	0.949 [0.851, 0.983]	2.40	2.68	−10.57 to 2.74	6.65	3.67 [1.65, 5.68]	0.943 [0.839, 0.980]	2.57	2.90	−3.46 to 10.8	1.04	1.01
Cadence (steps min^{-1})	−2.16 [−4.04, −0.28]	0.860 [0.620, 0.953]	2.30	1.96	−8.54 to 4.22	6.38	−1.66 [−2.74, −0.58]	0.952 [0.864, 0.984]	1.38	1.16	−5.49 to 2.17	0.99	−0.85
Stride Length (m)	−0.04 [−0.07, −0.02]	0.968 [0.904, 0.990]	0.03	1.96	−0.13 to 0.05	0.08	0.08 [0.06, 0.11]	0.962 [0.891, 0.987]	0.04	2.68	−0.02 to 0.18	1.06	1.63
Gait cycle (s)	0.02 [0.00, 0.04]	0.843 [0.581, 0.947]	0.02	1.95	−0.04 to 0.08	0.06	0.01 [0,0.02]	0.957 [0.878, 0.985]	0.01	0.99	−0.02 to 0.04	1.01	0.86
Single Limb Support Right (s)	0.01 [0;00, 0.02]	0.805 [0.497, 0.933]	0.01	2.67	−0.02 to 0.04	0.03	−0.02 [−0.03, −0.01]	0.614 [0.168, 0.851]	0.01	2.62	−0.05 to 0.01	0.95	−1.37
Single Limb Support Left (s)	0.01 [0.00, 0.02]	0.870 [0.644, 0.956]	0.01	2.60	−0.02 to 0.04	0.03	−0.01 [−0.03, 0]	0.431 [−0.085, 0.764]	0.02	5.21	−0.06 to 0.03	0.96	−0.63
Single Limb Support Right (%GC)	0.17 [−0.36, 0.7]	0.844 [0.584, 0.947]	0.65	1.79	−1.63 to 1.98	1.8	−2.6 [−3.43, −1.77]	0.626 [0.187, 0.857]	1.06	2.81	−5.54 to 0.34	0.93	−1.73
Single Limb Support Left (%GC)	0.09 [−0.29, 0.47]	0.910 [0.745, 0.970]	0.46	1.23	−1.2 to 1.38	1.28	−1.87 [−3.03, −0.71]	0.334 [−0.196, 0.713]	1.48	3.88	−5.96 to 2.22	0.95	−0.90
Swing Phase Right (%GC)	0.09 [−0.32, 0.49]	0.897 [0.711, 0.966]	0.49	1.31	−1.29 to 1.46	1.36	−1.8 [−2.78, −0.81]	0.496 [−0.002, 0.797]	1.26	3.31	−5.28 to 1.69	0.95	−1.01
Swing Phase Left (%GC)	0.18 [−0.32, 0.69]	0.865 [0.631, 0.954]	0.62	1.70	−1.52 to 1.89	1.72	−2.61 [−3.5, −1.71]	0.559 [0.086, 0.827]	1.14	3.02	−5.76 to 0.55	0.93	−1.62
Stance Phase Right (%GC)	−0.08 [−0.49, 0.32]	0.897 [0.712, 0.866]	0.49	0.78	−1.45 to 1.29	1.36	1.79 [0.81, 2.78]	0.496 [−0.002, 0.797]	1.26	2.04	−1.69 to 5.28	1.03	1.01
Stance Phase Left (%GC)	−0.17 [−0.68, 0.33]	0.862 [0.626, 0.954]	0.62	0.98	−1.89 to 1.54	1.72	2.59 [1.71, 3.48]	0.561 [0.088, 0.827]	1.13	1.81	−0.55 to 5.74	1.04	1.62
Double Limb Support Right (%GC)	−0.3 [−1.26, 0.65]	0.838 [0.569, 0.945]	1.17	4.52	−3.55 to 2.94	3.24	4.04 [2.3, 5.77]	0.505 [0.010, 0.801]	2.21	9.17	−2.1 to 10.18	1.18	1.29
Double Limb Support Left (%GC)	−0.27 [−1.09, 0.54]	0.880 [0.669, 0.960]	1.00	3.84	−3.04 to 2.49	2.77	4.02 [2.71, 5.33]	0.689 [0.292, 0.884]	1.68	6.93	−0.63 to 8.66	1.18	1.70

%GC: percentage of gait cycle; CI: confidence interval; ICC: intra class coefficient; LoA: limits of agreement; m: meter; min: minute; s: second; SDC: smallest detectable change; SEM: standard error of measurement; SEM%: standard error of measurement as percentage of the mean.
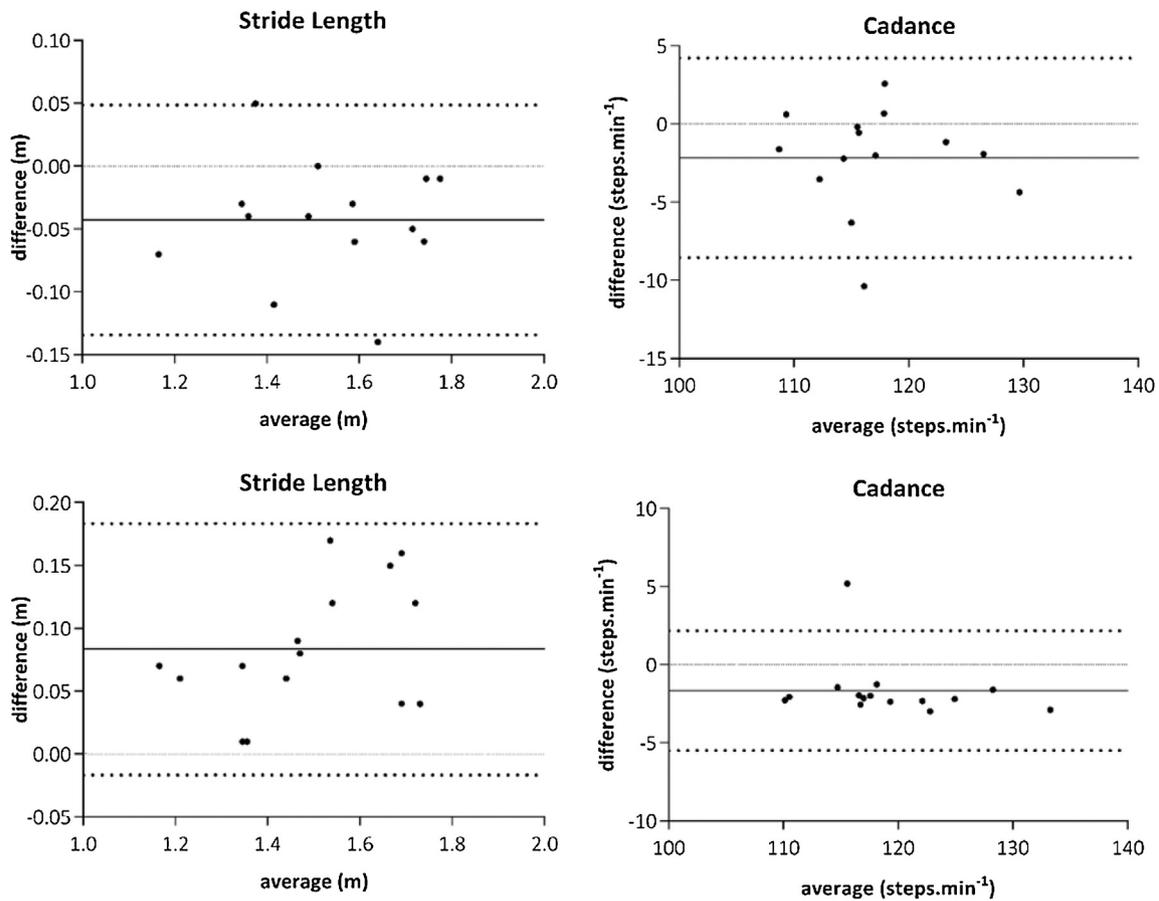
Fig. 1. Bland-Altman plots for stride length and cadence, comparing test-retest of the Stride Analyzer (above) and comparing the Stride Analyzer with the Vicon (below). Lines represent mean of the differences (solid) and limits of agreement (dotted) (m: meter; min: minute).

protocol was based on the lower body Plug-in-gait marker set which was used to define gait cycle events. Marker labeling and trajectory reconstruction were performed using Nexus 1.8.5 (Oxford Metrics, UK) and filtered using Woltring filtering routine (Predicted MSE value 10) [9]. Gait cycle events (i.e. initial contact, toe-off) were calculated from five force plates (AMTI0R6 Series— 1000 Hz, detection-threshold 20N). Plug-in-gait pipeline is used to determine TS gait parameters (LANK, RANK = posterior marker label; LTOE, RTOE = anterior marker label).

2.4. Experimental set-up

Infrared sensors of the SA were positioned at the 3rd and 9th meter of a 12 m walkway, indicating the assessment area. The first 3 m of each trial were used to achieve self-selected walking speeds. During eight trials, the SA recorded gait parameters. Subsequently, the markers of the motion capture system were attached to both shoes. Next, subjects walked for eight trials during which both instruments recorded simultaneously the gait parameters.

2.5. Data processing

Calibrated and synchronized Bonita cameras (Bonita-720 C– 100 Hz) were used to synchronize gait cycles recorded by both systems. Hence, two or three complete strides per trial were identified. The markers on the shoes were used to calculate Vicon TS parameters by using Nexus software 1.8.5 and the Plug-in-gait marker set.

2.6. Statistical methods

Intra-class correlation coefficients (ICC) (consistency values) were calculated for reliability (2,1) and for concurrent validity (3,1). In addition, the mean of the differences between 2 trials (i.e. bias) was calculated. Also the standard deviation of these differences was calculated (SD_{bias}) to determine the limits of agreement (bias $\pm$ 1.96 $\times$ SD_{bias}) [10]. Z-scores were also calculated. The standard error of measurement (SEM = $SD_{bias}/\sqrt{2}$) is reported as percentage of the mean (SEM%) [11]. In addition, the smallest detectable change (SDC), defined as 1.96 $\times$ SD_{bias}, was calculated. The ratio between the two devices was calculated. Bland-Altman graphs were plotted with GraphPad-Prism 6 software and statistical analyses were performed with IBM SPSS 23 software.

3. Results

3.1. Subjects

Fifteen participants were analyzed. Test-retest data of one person was discarded due to technical problems. Consequently, data of 15 and 14 participants were analyzed for validity and test-retest reliability, respectively. At least four trials per subject were used in the analyses.

The mean age of the participants was 65 years (8.5 SD) and the mean body mass index was 27 kg m^{-2} (4.1 SD). Forty percent had OA in the left knee, 27% in the right knee and 33% had bilateral knee

OA. All had radiographic signs of OA with Kellgren & Lawrence grades 1 (N = 6), 2 (N = 4), 3 (N = 2) or 4 (N = 2). Two patients had knee malalignment (valgus (N = 1), varus (N = 1)) but the majority had neutral knees (N = 12).

The mean values of all trials for TS variables are reported in Table 1.

3.2. Reproducibility

SA showed good reliability for all TS parameters with ICC values ranging from 0.805 (single limb support right) to 0.949 (velocity) (Table 2). The SEM values also provided support for good agreement (SEM% values ranging from 0.78% (stance phase right (%GC)) to 4.52%) (double limb support right (%GC)). The Bland-Altman plots of the stride length and the cadence are provided in Fig. 1 (see Appendix B in Supplementary material for more plots).

3.3. Validity

Good agreement between SA and Vicon was found for the following TS parameters: velocity, cadence, stride length and gait cycle (Table 2). All other gait parameters showed low ICC values (<0.689). The Bland-Altman plots of the stride length and the cadence are provided in Fig. 2 (see Appendix B in Supplementary material for more plots).

4. Discussion

This is the first study analyzing reproducibility and concurrent validity of the SA in patients with knee OA. The SA showed good agreement between two repeated measures. In addition, the concurrent validity with the motion capture instrument Vicon was found good for the following TS parameters: velocity, cadence, stride length and gait cycle (ICC ≥ 0.943 & SEM% ≤ 2.90). Other gait parameters were less reliable (ICC ≤ 0.689, SEM% ≤ 9.17).

Our findings regarding reproducibility are in line with studies investigating the SA in patient groups different from knee OA [2]. Since no data on the validity of this device has previously been reported, our results cannot be confirmed nor argued by other studies. One of the assets of this study is that the concurrent validity of the SA has been investigated by comparing its output to the measurements of the motion capture system Vicon, which is considered the gold standard [12].

Some limitations regarding this study exist. Although our sample size is comparable to other validation studies, a relatively small sample size was used in this study. Therefore we were not able to stratify subjects based on clinical characteristics that previously have been related to altered gait in knee OA [4,5]. To counter the limitation of not stratifying, we reported information on the specific patient characteristics.

5. Conclusions

The SA showed good reproducibility and had good concurrent validity with the motion capture instrument for velocity, cadence, stride length and gait cycle in subjects with symptomatic knee OA.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.gaitpost.2016.06.039.

Conflicts of interest

The authors declare that they have no conflicts of interest in the authorship or publication of this contribution.

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