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Original article

Validation of a novel activity monitor in impaired, slow-walking, crutch-supported patients

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ABSTRACT

Background: A growing need in clinical practice of rehabilitation and orthopaedic medicine is for objective outcome tools to estimate physical activity. Current techniques show limited validity or are too demanding for routine clinical use. Accelerometer-based activity monitors (AMs) have shown promise for measuring physical activity in healthy people but lack validity in impaired patients.
Objectives: This study aimed to validate an accelerometer-based AM in impaired, slow-walking, crutch-supported patients after total joint arthroplasty (TJA).
Methods: Shortly after TJA, patients who were safely mobilized with 2 crutches and 8 healthy participants completed a trial of different activities while wearing the AM on the lateral upper leg and being videotaped. Outcome variables (e.g., time walking, number of gait cycles, sit-stand-sit transfers) were compared to video recordings, and sensitivity, predictive value and mean percentage difference (MPD) values were calculated.
Results: We included 40 patients (mean age: 65 ± 9 years; mean BMI: 30 ± 6 kg/m^2; male:female ratio: 18:22) and 8 healthy participants (mean age: 49 ± 20 years; mean BMI: 23 ± 0.7 kg/m^2; male:female ratio: 5:3). The AM showed excellent sensitivity (> 95%) and predictive value (> 95%) in identifying activities (e.g., walking, sitting, resting) and detecting the number of gait cycles and sit-stand-sit transfers (mean percentage difference: ±2%). Detection of number of steps ascending and descending stairs and cadence was more difficult but still showed good results (mean percentage difference: ±7%).
Conclusions: This is the first validation study to assess physical activity with an AM in impaired, slow-walking, crutch-supported patients. The AM was a valid tool for measuring physical activity in these patients. The tool may help in evaluating and optimizing rehabilitation programs for patients after TJA, those recovering from stroke or chronic impaired patients.

1. Introduction

Physical activity is an important determinant of health and well-being and inactivity is strongly associated with morbidity and mortality [1,2]. Inactivity was identified by the World Health Organization [3] as the fourth strongest risk factor for mortality. Several diseases reduce physical activity, osteoarthritis being one of the leading causes and affecting 9% of the population [4]. Restoration of function and activity in patients with these diseases is one of the main goals for clinicians and is specific for patients with osteoarthritis after total joint arthroplasty (TJA). Monitoring physical activity before, shortly after and in late follow-up after TJA is crucial for evaluating rehabilitation, assessing social participation and determining the effectiveness of the interventions in evidenced-based practice.

Self-reported questionnaires are widely used to assess physical activity. Although they are inexpensive and easy to use, they show limited validity and reliability and are subject to bias; they largely overestimate activity [5–7]. In contrast, the gold standards in assessing physical activity in terms of energy expenditure – ingestion of double labeled water, room calorimetry and indirect calorimetry [8] – are time-consuming, costly and technically too demanding for routine clinical use. Furthermore, these techniques do not provide specific information on lower-limb activity or type of activity such as walking, stair climbing or cycling.

Portable sensors have evolved considerably over the years, from simple step counters to accelerometer-based activity monitors (AMs) combined with heart rate monitors, inertia-based monitors

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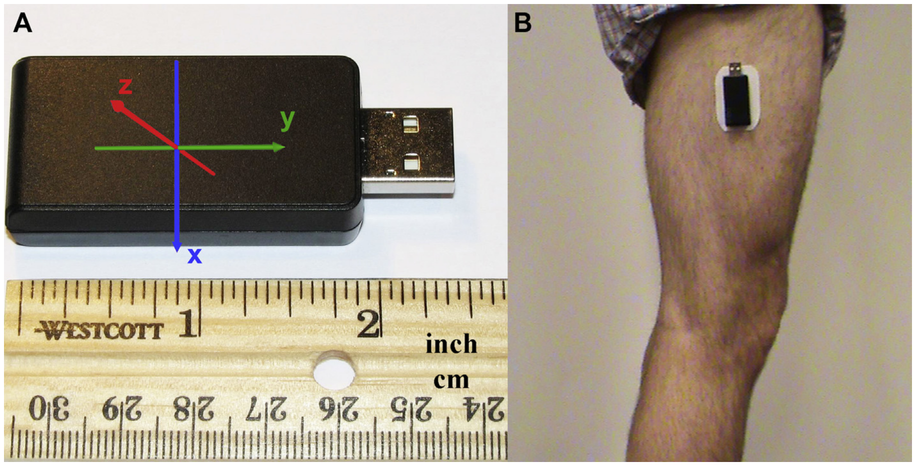

Fig. 1. The 3D accelerometer (USB accelerometer X16-mini, Gulf Coast Data Concepts, Waveland, MS, USA).

and GPS trackers [9–12]. Most of these devices are designed to give an estimation of energy expenditure [13] or activity counts [14]. Although they provide data on general physical activity levels, they do not provide information about specific lower-limb motor activities such as walking, transfers from sit to stand or climbing stairs. Monitoring these tasks is fundamental for assessing physical activity in patients with functional limitations in lower extremities.

A number of available AMs can identify specific activities such as sitting, lying down, standing and walking, with reasonably good accuracy [6,15,16], even in free-living settings [17,18]. Accelerometer-based activity monitoring in impaired patients or shortly after TJA poses an additional challenge. Because these patients move slowly and are crutch-supported, the magnitude of acceleration signals produced by activities will be lower and more difficult to detect. Several validation studies of slow-walking healthy people [19] and patients with chronic obstructive pulmonary disease [6,20], older adults with walking aids [21,22] and patients with rheumatoid arthritis [23] showed poor validity of such monitoring in detecting the number of steps or transitions. Recently, good results have been achieved in slow-walking but only healthy people [24,25]. Moreover, physical activity of patients after TJA has been monitored during only late follow-up [26–28]. Therefore, monitoring physical activity in impaired patients requires the validation of a new AM.

The aim of this study was to validate a novel single-sided AM in impaired, slow-walking, crutched-supported patients after TJA.

2. Materials and methods

To validate the AM in impaired and crutched-supported walking, we included patients who gave consent shortly after TJA, a median of 3 to 17 days (mean: 8.9 ± 5.3) after arthroscopy of the knee ($n = 23$) or hip ($n = 17$). Patients were able to safely move with 2 crutches. Eight healthy people without locomotor impairments were selected as a reference group and resembled fully recovered patients. The groups were not compared, so they were not matched. The study protocol was approved by the medical ethical committee of the Zuyderland medical center and all participants gave informed consent.

Patients and healthy people completed a trial in which they had to perform several activities consisting of walking, standing, resting (sitting and lying supine) and stair climbing (ascending and descending). Participants were free to complete these tasks in a random order, in their own way and at their preferred speed. Furthermore, the duration and number of repetitions of the activities depended on the person's condition. All activities were performed at least once. The trial was recorded on video, which was used for retrospective analysis. At the start and end of the trial, the AM and video recordings were synchronized by tapping on the sensor.

A commercially available, light-weight (18 g, $64 \times 25 \times 13$ mm) 3D accelerometer (USB accelerometer X16-mini, Gulf Coast Data Concepts, Waveland, MS, USA; Fig. 1a) was taped to the lateral non-affected upper leg of participants by using hypo-allergenic double-sided tape (3 M, product number 9917, Fig. 1b). The position of the sensor was at the mid-thigh between the trochanter and lateral condyle, with the y-axis of the sensor along the axis of the femur. We collected 12-bit data (range $\pm$ 2 g) at a sampling rate of 40 Hz; data were stored on an on-board memory micro-SD card. The raw acceleration signal was analyzed by using the inclinometer function of the accelerometer and algorithm-based peak detection methods in MATLAB as described [29]. Briefly, the accelerometer's orientation is calibrated during a period of level walking that is manually selected. Within this walking period, the average magnitudes of the 3 acceleration vectors and the gait cycle frequency (GCF) are derived to allow for further differentiation between activities. Differentiation between standing periods and resting periods is based on the direction of the gravitation vector and allows for identifying sit-to-stand transfers. Walking is differentiated from other upright activities (all classified as standing) by applying heuristic rules for the GCF. A walking period is classified with the detection of at least 5 consecutive heel strike peaks, with < 1.5 s between peaks for GCF > 0.6 Hz and < 3.0 s between peaks for GCF < 0.6 Hz. Furthermore, ascending and descending stairs is distinguished from level of walking based on the inclinometer function and the hip angle. An example of the raw acceleration signal is shown in Fig. 2.

Data analysis involved the type and duration of activities (walking, standing, resting, ascending and descending stairs) in seconds, the total number of activities including gait cycles (GCs), steps ascending and descending stairs, walking bouts (level walking, ascending and descending stairs) and transfers (from sitting or lying supine to straight). Activity intensity was assessed by walking cadence (GC $\times$ 2/min, determined over walking bouts of $\geq$ 10 GCs).

The video recordings were observed by one investigator. Activities were classified (type and duration) with a 1-s resolution, and GCs in level walking, steps descending and ascending stairs, bouts (level walking, ascending and descending stairs) and transfers were counted. In a pilot study of 20 patients observed by 2 investigators, inter-rater agreement in classifying activities

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