Samuel Gluck, Lee-anne S Chapple, Marianne J Chapman, Theodore J Iwashyna and Adam M Deane

A scoping review of use of wearable devices to evaluate outcomes in survivors of critical illness

Critical Care and Resuscitation, 2017; 19(3):197-204

A scoping review to determine the use of wearable devices to evaluate outcomes in survivors of critical illness

Authors:

Samuel Gluck[1,2], Lee-anne S Chapple[1,2], Marianne J Chapman[1,2], Theodore J Iwashyna[3,4] and Adam M Deane[1,5,6]

Affiliations:

[1] Discipline of Acute Care Medicine, University of Adelaide, Frome Rd, Adelaide, SA 5000, Australia.

[2] ICU Research Unit, Royal Adelaide Hospital, North Terrace, Adelaide, SA 5000, Australia.

[3] Department of Internal Medicine, University of Michigan, Ann Arbor, MI, USA

[4] Center for Clinical Management Research, VA Ann Arbor Health System, Ann Arbor, MI, USA.

[5] Intensive Care Unit, Royal Melbourne Hospital, The University of Melbourne, Grattan St, Parkville, VIC 3050, Australia.

[6] Department of Medicine, Royal Melbourne Hospital, University of Melbourne, Melbourne, VIC 3050, Australia.

Work performed at the Discipline of Acute Care Medicine, University of Adelaide.

Keywords:

Activity, Accelerometry, Critical illness, Outcomes, Technology

Acknowledgements: None

Disclaimer

This work does not necessarily represent the views of the US Government or Department of Veterans Affairs

Address for correspondence

Samuel Gluck, ICU Research Department, c/o Critical Care Services, Level 4 North Wing, Royal Adelaide Hospital, North Terrace, SA 5000

Phone – 08 8222 4624

Email – samuel.gluck@sa.gov.au

Second Email – lee-anne.costello@adelaide.edu.au

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Dr Gluck is supported by a Royal Adelaide Hospital A.R Clarkson Scholarship.

Ms Chapple is supported by a University of Adelaide Australian Postgraduate Award, a Royal Adelaide Hospital Dawes Top-Up Scholarship and a University of Adelaide Discipline of Acute Care Medicine Top-Up Scholarship.

Word count 2500

Abstract:

Objective

Technology may be a cost-effective method to assess functional outcomes in survivors of critical illness. The primary objective of this review was to determine the extent to which wearable device technology, such as smartphones, pedometry, accelerometry and global positioning systems (GPS), have been used to evaluate outcomes in Intensive Care Unit (ICU) survivors.

Design

Studies were included if they were performed in patients surviving ICU admission and measured outcomes using wearable devices.

Data Sources and Review Method

A scoping review searching CINALH, EMBASE, MEDLINE and PUBMED was performed.

Results

The seven studies identified were published since 2012, and were predominately descriptive (n=6) with one randomised controlled trial. All studies described outcomes in cohorts of relatively few participants [range: 11–51]. Duration to follow-up was mostly short, at a median time of three months post-ICU discharge [range: in-hospital to 27 years]. All studies used accelerometers to monitor patient movement; specifically physical activity (n=5), sleep quality (n=1), and infant movement (n=1). The accelerometers were bi-axial (n=3), uni-axial

(n=2), combined uni-axial (n=1) and tri-axial (n=1). Common outcomes evaluated were the number of participants walking for < 30 min/day, mean daily step-counts and walking speed.

Conclusions

While wearable devices have been infrequently used to measure physical activity in survivors of critical illness, all identified studies were published recently, suggesting the use of wearable devices may be increasing. Thus far, only accelerometry has been reported, and the wide variation in methodologies used and the outcomes measured limits synthesis of these data.

Highlights: (3-5 bullet points of core findings, max 85 characters)

- Accelerometers have been used to quantify physical activity following critical illness.
- The heterogeneity between studies prevents extensive comparisons.

Abbreviations:

Intensive Care Unit (ICU), Global Positioning System (GPS)

Introduction

Physical activity and function is frequently impaired in survivors of critical illness [1-11]. While functional capacity after critical illness is an important outcome, to date, both researchers and clinicians have relied upon labour-intensive techniques, such as the six-minute walk test and subjective patient-reported questionnaires, to quantify quality of life (QOL) and physical function [1-10]. Given the logistical challenges and expense associated with these methods there is a need to be able to accurately, yet efficiently, assess physical recovery in survivors of critical illness in a way that is meaningful to patients and clinicians.

Technological advances provide the potential to quantify physical activity in a real-life setting, and in a cost-effective manner. It is possible that quantifying mobility, using daily step-counts, or measuring how much time individuals spend at home, may provide a holistic and patient-centric assessment of physical function.

A number of relatively inexpensive and seemingly accurate pedometers and accelerometers are now available [12]. A pedometer measures the number of steps taken by an individual and an accelerometer responds to acceleration in either one, two or three planes (uni-, bi-, and tri-axial accelerometers, respectively). With the use of differing body mounting and algorithms, accelerometers can be used to assess sleep, the intensity and duration of activity, body position, steps and energy expenditure. They record data continuously, providing a more representative measure of activity. Furthermore, ambulatory global positioning system (GPS) devices record movement through location data. A smartphone contains a tri-axial accelerometer, a gyroscope, a compass, and a barometer, combining these sensors with

appropriate software applications (apps) and algorithms has the capacity to wirelessly transmit live data to researchers and clinicians. Such methodology is increasingly described in epidemiological studies, for example McConnell and colleagues recently report using a smartphone app to quantify physical activity from more than 20,000 healthy individuals [13].

Given the recent advances in technology of wearable devices that record physical activity, there has been growth in the number of researchers evaluating these devices across different healthcare settings. Accelerometers and pedometers have been used to assess physical activity in a variety of conditions including chronic obstructive pulmonary disease [14], cystic fibrosis [15], multiple sclerosis [16], diabetes [17] and joint replacement preoperative assessment [18]. To date, however, no review has summarised the current literature on wearable devices in survivors of critical illness.

We conducted a scoping review with the primary objective to evaluate whether wearable devices have been used to measure outcomes in survivors of critical illness. For the purpose of this review wearable devices included smartphones, pedometry, accelerometry and GPS. Our secondary objectives were to compare outcomes evaluated using wearable devices to more conventional methodologies and to evaluate usability in study participants.

Scoping Review Question

Have smartphones, pedometry, accelerometry or GPS been used to assess outcomes in patients who have survived an ICU admission?

Methods

Data sources and searches

On 9 May 2016 we conducted a scoping review of the literature using four online databases (CINALH, EMBASE, MEDLINE and PUBMED). The search criteria are provided in Supplementary Table 1 (online at cicm.org.au/journal.php). All MeSH terms were expanded for further terms and included in the search of all four databases. Reference lists of all retrieved papers were reviewed to identify other eligible studies not captured in the primary search.

Eligibility criteria

We included studies that reported outcomes in survivors of critical illness using wearable devices. We defined wearable devices as smartphones, pedometers, accelerometers, and GPS devices, based on our understanding of current technologies that could be used to assess outcomes following critical illness, which we defined as any condition necessitating ICU admission regardless of the presenting problem. No date restrictions were applied. We excluded studies that did not specify whether they were conducted in ICU survivors, did not report on the use of an aforementioned devices, and were not published in English.

Study selection

Duplicate citations were removed and titles and abstracts were independently screened for inclusion by two reviewers (SG and LC). If it was not clear from the abstract if the citation could be excluded, then the full-text article was obtained. Full-text manuscripts were

independently evaluated for eligibility. Disagreements were resolved by consensus or consultation with a third reviewer (AD).

Data extraction

Two reviewers (SG and LC) independently extracted data from included studies using a modified version of a standardised data collection form [19]. Information extracted included study characteristics (author, publication year, country, design, sample size), type/s of technology used, outcomes from the technology used, conventional outcomes compared to wearable devices, and study results.

Quality assessment

Risk of bias for observational studies was assessed using the Newcastle-Ottawa Scale. The Newcastle-Ottawa scores studies on three domains relating to the: selection of study groups; comparability of groups; and ascertainment of either the exposure or outcome of interest for case-control or cohort studies, respectively [20].

Usability of wearable devices

We defined usability as whether the wearable device provided a data point. We measured usability as the number of incomplete records, due to either user or device failure, out of the total number of participant data points**,** with a lesser number signifying greater usability.

Results

Study selection

Our search returned 1317 references, of which 526 were duplicates. Of the 791 abstracts reviewed, 747 did not meet the defined inclusion criteria and were excluded. Forty-four full-text articles were obtained and assessed for eligibility. Of these, 37 were excluded due to: patients were not admitted to ICU (n=10); studies were conducted during ICU admission and not in survivors (n=10); duplicate data (n=9), outcomes not reported (n=5) and only published in abstract form (n=3). Accordingly, seven studies were included in our review [21-27] (Figure 1).

Study characteristics

There were five prospective observational cohort studies [22, 23, 25-27], one case control study [21], and one randomised controlled trial [24] (Table 1). Three studies were nested within larger studies: two within RCTs [23, 27] and one within a longitudinal study [25]. All studies were published since 2012. Using the Newcastle-Ottawa Scale the quality of all the observational studies were low with the major limitation to these studies being their single cohort and/or descriptive nature.

Cohort studied

One study was conducted in neonates who survived ICU admission [24] and one was conducted in adults who survived an earlier ICU admission as neonates [21]. The remainder were in survivors of adult ICU (Table 1), and included various enrolment criteria such as severe sepsis, mechanical ventilation, or ICU length of stay >5 days. All studies described outcomes

in cohorts of relatively few participants [range; n= 11–51]. Only one study [25] included a calculation to determine sample size. The majority of studies evaluated their outcomes within three months of ICU discharge, although one measured at 18 months post- ICU, and one at a mean of 26 years [21, 25]. Borges et al and Guyer et al were the only investigators to report on outcomes at more than one time point [24, 26].

Usability of wearable devices

There were 8/301 records across all studies that failed to complete activity monitoring; four in Denehy's [27] study, three in McNelly's [25] study, and one in Edbrooke's [23] study, suggesting the devices were usable.

Technology reported

All studies used accelerometers to monitor activity. The bi-axial AMP331 was the most commonly used accelerometer, with bi-axial accelerometers being used by three groups of investigators [23, 25, 27], uni-axial accelerometers by two groups [22, 24], and combined uni-axial accelerometers [21] and tri-axial accelerometers were used by one group each [26].

Outcomes measured

Studies evaluated physical activity (n=5) [21, 23, 25-27], sleep quality (n=1) [22], and infant movement (n=1) [24]. Reported outcome measures are summarised in Table 1. Several studies reported multiple accelerometer outcomes. The physical activity outcomes measured varied and included simple assessments of body position [26], walking speed [23, 26], duration in dynamic activities [21], distance walked [23, 27], time spent walking [26], time spent inactive [26, 27] and steps [23, 25, 27]. Only daily step-count [25, 27], walking speed

[23, 26] and number of participants walking <30 minutes a day [26, 27] were reported in more than one study.

Associations with traditional outcome measures

Two studies reported direct correlations between outcomes measured using wearable devices and more 'traditional' outcomes, such as global reported QOL measures. There was a modest association between the total Physical Activity Scale for the Elderly (PASE) score and mean daily step-count (Spearman's rank coefficient (rho)=0.332 p=0.05) or distance walked (rho=0.313 p=0.05) [27]. Stronger correlations were shown between mean daily step-count and both the Physical Component Summary score (r^2=0.25, p<0.01) and Physical Function score (r^2=0.51 p<0.01) of the SF-36 and with the Clinical Frailty Scale (CFS) (r^2=0.55 p<0.01) [25]. McNelly [25] and Denehy [27] both reported that patients with chronic disease who survived ICU had reduced step-count compared to those without chronic disease.

Discussion

Our scoping review revealed that seven studies have reported on the use of wearable devices to measure outcomes in survivors of critical illness. However, as all identified studies were published within the last five years it appears that the use of wearable devices may be an emerging field of research. The use of wearable devices permits a high degree of 'usability' with only a small number of failed readings/absent data points.

Our review also revealed that the majority of studies in this field have been exploratory in nature, and conducted in small, often single, cohorts of patients, with short-term follow-up. Additionally, the quality of study design was modest. Only one RCT was identified, and three studies were nested in other studies. This would be consistent with an emerging field of research where exploratory studies frequently do not have the methodological rigor of large-scale RCTs [28].

Variety in outcomes reported

While the studies all utilised accelerometry to quantify outcomes, a wide variety of outcomes were measured and reported, such as sleep actigraphy [22] and movement assessment [24]. The outcome most frequently reported was locomotion. Even with this outcome, there was a lack of consensus between investigators on how this should be quantified. While locomotion was recorded in four studies [23, 25-27], the only commonly reported outcomes were mean daily step-count, distance walked, and the number of participants that walked for <30 minutes/day. This variation is expected during the initial phases of a methodology but over time it is important that consistency in core domains is established [29]. The findings of this

review highlight the need for the development of core outcome sets for measurement of physical activity in ICU survivors using technology.

We were surprised there was no utilisation of GPS data to create life-spaces [30], activity-spaces [31] or to quantify percentage time spent at home [32], as such measures have been used in other populations e.g. after surgery for peripheral vascular disease [33], spinal disorders [34], and in those with mental health issues [35]. The activity space is a geographic information systems construct that represents the environment an individual interacts with. Such measurements may provide an assessment of recovery from critical illness. We were also surprised that smartphones, with their associated apps, had not been used in any relevant study.

Accelerometer methodologies

Four identified studies reported on locomotion using algorithms to access raw accelerometer data to determine step data. Step data are increasingly reported in other healthcare settings [36-39]. It has been shown that uni-axial accelerometers are adequate for detecting heal strike [40] to calculate physical activity from walking, but this may under-estimate when assessing gait in slower walkers, particularly those with a shuffling gait [41]. It does, however, produce data that are patient-centered and easily interpreted by clinicians.

While using locomotion data may have its advantages, the accelerometer literature suggests that using centrally mounted tri-axial accelerometers to count activity frequency and intensity would provide the best estimate of total physical activity [40], and raises the suggestion of

using advanced modeling techniques combining accelerometer outputs to produce estimates of activity counts and energy expenditure [42].

Although less patient-focused, the use of total activity counts to estimate energy expenditure, taking into account intensity and frequency of all movements, rather than just energy expenditure, and hence physical activity, related to walking would, perhaps, provide a better assessment of physical activity. Notwithstanding the limitations of each methodology, the use of a single research methodology is ideal.

Relationships between outcomes obtained from wearable devices compared to other methodologies

It appears that there are fair associations between outcomes after critical illness measured using wearable devices compared with more 'traditional' methodologies, such as self-reported QOL questionnaires. In this review, we found stronger associations between subjective measures than between subjective and objective measures, the subjective assessment of sleep (Pittsburgh sleep quality index) had stronger correlations with the subjective assessments of health-related QOL (EQ-5D and SF-36), than with objective actigraphy measures [22], as did the subjective assessments of physical function (SF-36) with frailty (CFS) than with daily step-counts [25]. It is important, prior to the widespread implementation of step data into critical care research, to establish that measurement of physical activity after critical illness is both clinically important and related to functional outcomes of importance to patients, their care-givers, and the community.

Usability as an outcome for large trials

Although two studies [21, 22] reported that only a subset of patients used the wearable devices due to availability, potentially implying a cost limitation, the cost of follow-up using accelerometers has not been explicitly stated in any study. An AMP331 costs $1200 (and is no longer produced), a Sensewear accelerometer $120 and an Actiwatch 2 (4 is discontinued) $1500. This is likely to be prohibitively expensive for researchers conducting trials involving large numbers of patients and/or sites. Fortunately, however, this cost is likely to reduce over time. An example of the dynamic nature of the technology landscape is that two of the accelerometers used in the identified studies, which were conducted within the last five years, have already been discontinued. The rapid evolution of these technologies and dynamic pricing structures is evident in that 'market leaders' in the commercial space, such as the FitBit One ($130) and Flex ($89) are comparatively inexpensive, and have been shown to be accurate [12]. Therefore, these dynamic changes may reduce costs however, the rapid evolution in makes, models and function could hinder attempts to develop core outcomes and methodologies using these technologies.

Strengths and limitations

Our review is, to the best of our knowledge, the first to appraise the use of wearable devices in ICU survivors. The strengths are: our search technique was relatively comprehensive; we evaluated studies for bias and quality and we used a standardised data extraction tool. However, we only accessed English language literature and moreover, there may be other wearable devices we are not aware of, and were not included in our search terms. Finally, the considerable heterogeneity of differing populations, wearable device outcomes, and time-point to follow-up between studies limits any firm conclusions.

Conclusions

Currently, wearable devices are infrequently used to report outcomes from survivors of critical illness. While accelerometry was the only technology reported, there was considerable variation as to the type of accelerometer used, the specific outcome reported, and the time point that observations were made.

References

1. Herridge MS, Tansey CM, Matte A *et al*: Functional disability 5 years after acute respiratory distress syndrome. *N Engl J Med* 2011, 364:1293-1304.
2. Winters BD, Eberlein M, Leung J *et al*: Long-term mortality and quality of life in sepsis: a systematic review. *Crit Care Med* 2010, 38:1276-1283.
3. Iwashyna TJ, Cooke CR, Wunsch H *et al*: The Population Burden of Long-Term Survivorship after Severe Sepsis Among Older Americans. *J Am Geriatr Soc* 2012, 60:1070-1077.
4. Karlsson S, Ruokonen E, Varpula T *et al*: Long-term outcome and quality-adjusted life years after severe sepsis. *Crit Care Med* 2009, 37:1268-1274.
5. Steenbergen S, Rijkenberg S, Adonis T *et al*: Long-term treated intensive care patients outcomes: The one-year mortality rate, quality of life, health care use and long-term complications as reported by general practitioners. *BMC Anesthesiology* 2015, 15:142.
6. Unroe M, Kahn JM, Carson SS *et al*: One-year trajectories of care and resource utilization for recipients of prolonged mechanical ventilation: a cohort study. *Annals of internal medicine* 2010, 153:167-175.
7. Stevens RD, Dowdy DW, Michaels RK *et al*: Neuromuscular dysfunction acquired in critical illness: a systematic review. *Intensive Care Med* 2007, 33:1876-1891.
8. Bagshaw SM, Stelfox HT, McDermid RC *et al*: Association between frailty and short- and long-term outcomes among critically ill patients: a multicentre prospective cohort study. *CMAJ* 2014, 186:E95-102.
9. Secombe PJ, Stewart PC, Brown A: Functional outcomes in high risk ICU patients in Central Australia: a prospective case series. *Rural Remote Health* 2013, 13:2128.
10. Iwashyna TJ, Ely EW, Smith DM *et al*: Long-term Cognitive Impairment and Functional Disability Among Survivors of Severe Sepsis. *JAMA* 2010, 304:1787-1794.

11. Iwashyna TJ: Survivorship will be the defining challenge of critical care in the 21st century. *Annals of internal medicine* 2010, 153:204-205.
12. Case MA, Burwick HA, Volpp KG *et al*: Accuracy of smartphone applications and wearable devices for tracking physical activity data. *JAMA* 2015, 313:625-626.
13. McConnell MV, Shcherbina A, Pavlovic A *et al*: Feasibility of obtaining measures of lifestyle from a smartphone app: The myheart counts cardiovascular health study. *JAMA Cardiology* 2016.
14. Dallas MI, McCusker C, Haggerty MC *et al*: Using pedometers to monitor walking activity in outcome assessment for pulmonary rehabilitation. *Chronic Respiratory Disease* 2009, 6:217-224.
15. Quon BS, Patrick DL, Edwards TC *et al*: Feasibility of using pedometers to measure daily step counts in cystic fibrosis and an assessment of its responsiveness to changes in health state. *Journal of cystic fibrosis : official journal of the European Cystic Fibrosis Society* 2012, 11:216-222.
16. Shammas L, Zentek T, von Haaren B *et al*: Home-based system for physical activity monitoring in patients with multiple sclerosis (Pilot study). *Biomedical Engineering Online* 2014, 13:10-24.
17. Diedrich A, Munroe DJ, Romano M: Promoting physical activity for persons with diabetes. *Diabetes Education* 2010, 36:132-140.
18. Naal FD, Impellizzeri FM: How active are patients undergoing total joint arthroplasty?: A systematic review. *Clin Orthop* 2010, 468:1891-1904.
19. Joanna-Briggs-Institute: Methodology For JBI Scoping Reviews 2015. http://joannabriggs.org, Accessed 1st May 2016.
20. GA Wells BS, D O'Connell, J Peterson, V Welch, M Losos, P Tugwell: The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. www.ohri.ca/programs/clinical_epidemiology/oxford.asp Accessed 3rd September 2016.
21. Van der Cammen-van Zijp MHM, Spoel M, Laas R *et al*: Exercise capacity, daily activity, and severity of fatigue in term born young adults after neonatal respiratory failure. *Scandinavian Journal of Medicine and Science in Sports* 2014, 24:144-151.
22. Solverson KJ, Easton PA, Doig CJ: Assessment of sleep quality post-hospital discharge in survivors of critical illness. *Respir Med* 2016, 114:97-102.
23. Edbrooke L, Lythgo N, Goldsworthy U *et al*: Can an accelerometer-based monitor be used to accurately assess physical activity in a population of survivors of critical illness? *Global journal of health science* 2012, 4:98-107.
24. Guyer C, Huber R, Fontijn J *et al*: Cycled light exposure reduces fussing and crying in very preterm infants. *Pediatrics* 2012, 130:e145-151.
25. McNelly AS, Rawal J, Shrikrishna D *et al*: An Exploratory Study of Long-Term Outcome Measures in Critical Illness Survivors: Construct Validity of Physical Activity, Frailty, and Health-Related Quality of Life Measures. *Crit Care Med* 2016, 44:e362-369.
26. Borges RC, Carvalho CR, Colombo AS *et al*: Physical activity, muscle strength, and exercise capacity 3 months after severe sepsis and septic shock. *Intensive Care Medicine* 2015, 41:1433-1444.
27. Denehy L, Berney S, Whitburn L *et al*: Quantifying Physical Activity Levels of Survivors of Intensive Care: A Prospective Observational Study. *Phys Ther* 2012, 92:1507-1517.

28. Eldridge SM, Lancaster GA, Campbell MJ *et al*: Defining Feasibility and Pilot Studies in Preparation for Randomised Controlled Trials: Development of a Conceptual Framework. *PLoS One* 2016, 11.
29. Hodgson CL, Turnbull AE, Iwashyna TJ *et al*: Core Domains in Evaluating Patient Outcomes After Acute Respiratory Failure: International Multidisciplinary Clinician Consultation. *Phys Ther* 2016.
30. Wan N, Qu W, Whittington J *et al*: Assessing smart phones for generating life-space indicators. *Environment and Planning B: Planning and Design* 2013, 40:350-361.
31. Hirsch JA, Winters M, Clarke P *et al*: Generating GPS activity spaces that shed light upon the mobility habits of older adults: a descriptive analysis. *International Journal of Health Geographics* 2014, 13:51-64.
32. Liddle J, Ireland D, McBride SJ *et al*: Measuring the Lifespace of People With Parkinson's Disease Using Smartphones: Proof of Principle. *JMIR mHealth and uHealth* 2014, 2:e13.
33. 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.
34. Bostelmann R, Schneller S, Cornelius JF *et al*: A new possibility to assess the perioperative walking capacity using a global positioning system in neurosurgical spine patients: a feasibility study. *European Spine Journal* 2016, 25:963-968.
35. Brusilovskiy E, Klein LA, Salzer MS: Using global positioning systems to study health-related mobility and participation. *Social Science & Medicine* 2016, 161:134-142.
36. Saunders T, Campbell N, Jason T *et al*: Objectively Measured Steps/Day in Patients with Chronic Obstructive Pulmonary Disease: A Systematic Review and Meta-Analysis. *Journal of physical activity & health* 2016:1-25.
37. Byrom B RD: Measuring free-living physical activity in COPD patients: Deriving methodology standards for clinical trials through a review of research studies. *Contemporary Clinical Trials* 2016, 47:172-184.
38. Tudor-Locke C, Hart TL, Washington TL: Expected values for pedometer-determined physical activity in older populations. *The International Journal of Behavioral Nutrition and Physical Activity* 2009, 6:59-59.
39. Darvall JN, Parker A, Story DA: Feasibility and acceptability of remotely monitored pedometer-guided physical activity. *Anaesth Intensive Care* 2016, 44:501-506.
40. Bouten CV, Westerterp KR, Verduin M *et al*: Assessment of energy expenditure for physical activity using a triaxial accelerometer. *Med Sci Sports Exerc* 1994, 26:1516-1523.
41. Bassett DR, Jr., Ainsworth BE, Leggett SR *et al*: Accuracy of five electronic pedometers for measuring distance walked. *Med Sci Sports Exerc* 1996, 28:1071-1077.
42. Chen KY, Bassett DR, Jr.: The technology of accelerometry-based activity monitors: current and future. *Med Sci Sports Exerc* 2005, 37:S490-500.

STRING 1	STRING 2
Critical care	Mobile phone$
Critical$ ill$	Cell$ phone$
Intensive care$	Smartphone$
ICU$	Smart phone$
Intensive therapy	Pedomet$
ITU$	Step count$
	Acceleromet$
	Actigraph$
	GPS
	Global positioning system$
	Cell$ telephone$
	Life space$
	Activity space$

Supplemental Table 1: Search terms used in each database. $ corresponds to the appropriate truncation command in each database.

Lead author	Year	Study Design	Cohort studied	Number of patients	Wearable Device	Time to follow-up	Duration of observation	Observations from wearable device	Other outcomes	Associations
Solverson	2016	Prospective observational cohort study	Adults, >4 day ICU LoS. Excluded TBI, neurocognitive disorders, acute strokes, patients living a distance from the hospital	55 (11 sleep actigraphy)	Sleep actigraphy	3 mo post-hospital discharge	3 nights	Sleep/Awake cycles -Mean total sleep time – 6.15hrs - Sleep efficiency 78% - Number of awakenings (duration) 11 (7mins) - Sleep onset latency – 12 mins.	Sleep Quality - PSQI, ESS. HRQOL; EQ-5D, SF-36. Depression/anxiety; HADS.	No association between total sleep time, sleep efficiency or sleep disruptions and PSQI or PSQI component scores. Significant association with APACHE II score. Total sleep time had no association with HADS, ED-5D individual domains or MCS or PSC.
Edbrook	2012	Prospective observational cohort study (nested in RCT)	Adults, sourced from a concurrent RCT, able to walk >5m without assistance	20	AMP331 biaxial accelerometer	Post-ICU hospital ward	Point in time, in hospital assessment	Reported distance walked, steps taken and walking speed.	Direct observation	Slight underestimations of walking distance (2.79 (walk 1) – 3.11 (walk 2) m over a total of 90m) and walking speed (28.87 cm/s) and a slight overestimation of step-count (0.92, 95% CI -3.27 – 5.11)
Guyer	2012	Randomised control trial	Neonates <32 weeks gestational age	37	Actiwatch mini and Actiwatch AW4	5 and 11 wks post-term corrected age	10 days at each time point.	Reduced activity count per 24 hrs in the DL group at 5 and 11 wks. No between group difference for activity count/night or day. Age-effect noted with increased activity between 5 and 11 wks	Sleep and crying behavior every 5 mins in an auditory diary (3 days), Weight	No correlations with wearable devices were reported.

Van Der Cammen-van Zijp	2014	Retrospective case control study	Adult survivors of neonatal resp distress,(27 with CDH, 30 without)	57 (28 activity monitoring)	4 uni-axial accelerometers	Unplanned follow-up of PICU survivors in adulthood (Mean 26.7 years)	2 days	Reduced duration of dynamic activities in the CDH group. No difference for mean motility and motility during walking. No significant differences between groups	Lung Function - Spirometry Exercise testing – CPET Fatigue – FSS HRQOL - LIFE-H 3.0 and SF36	No correlations with wearable devices were reported
McNelly	2016	Prospective observational cohort study (nested in longitudinal outcomes study)	Adult, >48 hrs ventilation, >7 d ICU LoS. Excluded;- pregnant; lower limb amputees; disseminated cancer, neuromuscular pathology	30 pts (27 provided data) and 30 age and gender matched controls	SenseWear bi-axial accelerometer,	18 mo post-ICU discharge	>5 days, including one weekend day.	Daily step-count was half that of healthy controls. Pre-existing chronic disease was associated with lower step-counts	HRQOL - SF-36, Frailty - CFS	Steps/d vs SF-36 PF r^2=0.51, vs SF36 PCS r^2=0.25, vs CFS r^2=0.55. Variation in steps vs SF-36 PF r^2=0.24 vs CFS – r^2=0.32.
Borges	2015	Prospective observational cohort study	Adult, severe sepsis or septic shock, able to walk without assistance pre-admission, able to complete 2 assessments at ICU D/C Excluded;- previous stroke, neurological disease, TBI, SAH, SCI, fractured limbs or amputation, terminal illness	72 at hospital D/C 51 at 3mo follow-up and 50 healthy controls.	Dynaport tri-axial accelerometer	Prior to hospital discharge and 3 mo post discharge	2 consecutive days at both time points.	Septic patients had a lower walking time in at both time points compared to healthy individuals. Patients were more inactive (sitting or lying) on the ward, than at 3-months. Walking intensity was lower after hospital discharge than healthy individuals. 40% of septic patients walked <30 mins/day vs 15% of healthy individuals	Muscle strength: inspiratory muscles - MIP, handgrip (dominant hand dynamometry) and quadriceps (dynamometry) Exercise capacity - 6MWT	No associations between accelerometer data and any other variable during hospital admission or at 3-mo

Denehy	2012	Prospective observational cohort study, (nested in a RCT)	Adult, >5 d ICU LoS, English speaker, live within 50km, Participation agreed by the attending intensivist. Excluded neurological, spinal or musculoskeletal dysfunction.	49 accelerometer data 45 PASE data	AMP 331 Accelerometer	2 mo post ICU discharge	7 days	Participants took 4,894 (SD – 3,070) steps/day, 80% took <7500 and only 6% >10,000 steps/day. Only 54% of steps were taken in the locomotion category. Median distance walked was 1.69km. 90% of their time was spent inactive, 3% of the time was spent in the locative category. 63% of the cohort spent <30 mins/d in the locomotive category.	Lifestyle - PASE questionnaire Exercise capacity - 6MWD Manual Muscle strength - Timed up and go test (TUG)	Fair correlation between total PASE and mean steps/day rho=0.332 and mean distance walked rho=0.313 at p=0.05. Fair correlation between PASE occupation sub-score and daily steps rho=0.332. Fair correlation between walking <30 mins/day from PASE and steps (rho=0.345) and distance (rho=0.344). 6MWD and SF-36 PF was associated with walking time and steps/da in a univariate analysis, in the multi-variant analysis this was confounded by the presence of chronic disease.

Table 1 - Details of the peer reviewed articles included in our scoping review – AA – Age Adjusted, 6MWD – Six-Minute Walk Distance, CDH – Congenital Diaphragmatic Hernia, d – Day, D/C - Discharge, CFS – Clinical Frailty scale, CL – Cycled Light, CPET – Cardo-Pulmonary Exercise Testing, DL – Dim Light, D_{LCO} – Diffusion capacity of the lung for carbon monoxide,EQ-5D – EurolQol-5D, ESS – Epworth Sleepiness Scale, FEV_1 – Forced expiratory volume in 1 sec, FSS – Fatigue Severity Score, FVC – Forced Vital Capacity, HADS – Hospital Anxiety and Depression Scale, MIP – Maximal Inspiratory Pressure, MCS – Mental Composite Score of SF-36, PADL – Physical Activities of Daily Life, PASE – Physical activity scale for the elderly questionnaire, PCS – Physical Composite Score of SF-36, PSQI – Pittsburg Sleep Quality Index, SCI – Spinal Cord Injury, SDS – Standard Deviation Scores, SF-36 – Short-Form 36, TBI – Traumatic Brain Injury, TPDA – Time Post-Discharge Adjusted, TUG – Timed Up and Go Test, V_A – Alveolar volume, VAT – Ventilatory anaerobic threshold.

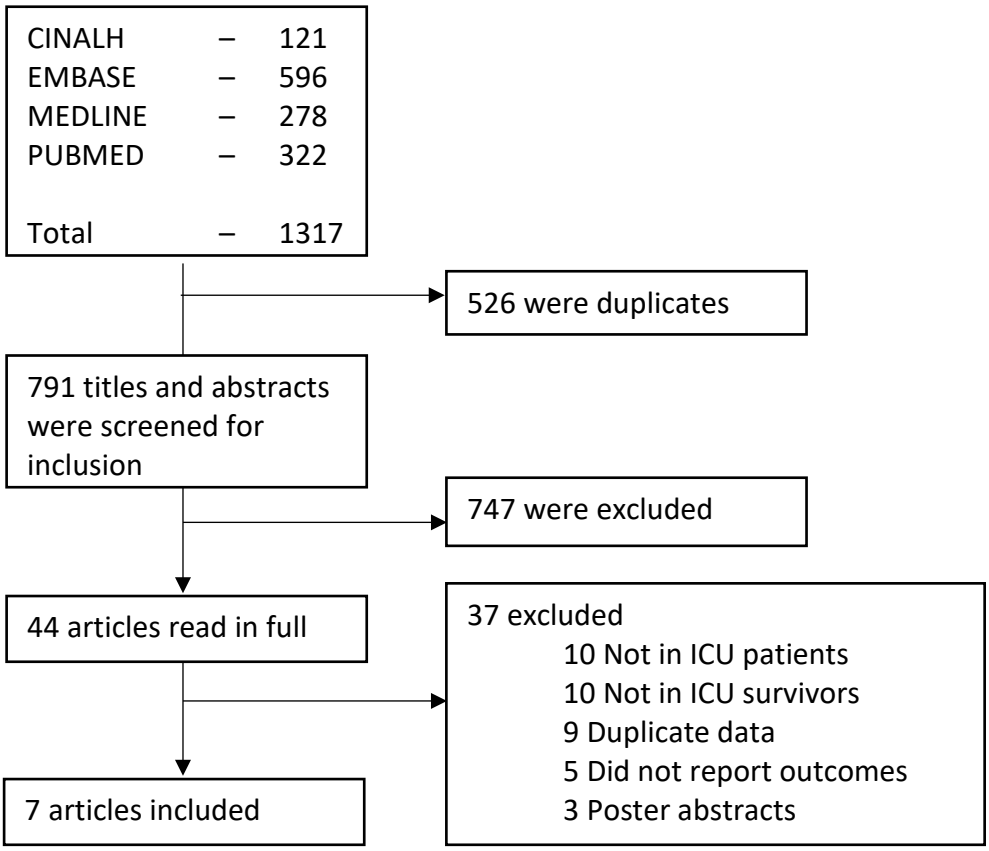

Figure 1 Flow diagram for selection of studies. ICU - Intensive Care Unit.