



The Use of Data Collected from mHealth apps to inform Evidence-based Quality Improvement: An Integrative Review

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3 **Descriptive Title:** The Use of Data Collected from mHealth apps to
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5 inform Evidence-based Quality Improvement: An Integrative Review.
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11 **Short title:** Using data from mHealth apps to inform Evidence-based
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14 Quality Improvement
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18 **ABSTRACT**

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20 **Background:** The global acceptance and use of technology in healthcare has resulted
21
22 in an abundance of mobile health (mHealth) applications (apps) available for use in
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24 the delivery and improvement of care. With so many apps available to patients and
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26 clinicians, it is important to understand how data from apps is being used to inform
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28 quality improvement in practice.
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34 **Aim:** The aim of this integrative review is to establish current knowledge of how
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36 mHealth apps are used to produce data to inform quality improvement in
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38 healthcare.
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44 **Method:** Scopus, Web of Science, CINAHL and Medline Plus Full Text databases were
45
46 searched for peer-reviewed papers written in English. The inclusion criteria
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48 comprised full text, empirical research studies relating to mobile health application
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50 use (not development) in clinical care.
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3 **Results:** 19 studies met inclusion criteria. The functions of the apps outlined in the
4
5 studies can be summarised into four different categories; communication, illness
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7 management, clinical management and education/information. The types of data
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9 collected by the apps included numerical, textual, photographic, and graphical with
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11 several apps able to collect a variety of data types. Analysis of the studies showed
12
13 that although data collection is rarely outlined as the explicit purpose of mHealth
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15 apps, data collected through such technology is and can be used to inform practice
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17 change both in real-time and retrospectively.
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23 **Linking Evidence to Action:** This review highlights while this is an emerging area,
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25 data obtained from mHealth apps can and is being used to inform quality
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27 improvement in healthcare. Further research is required in this area to adequately
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29 understand how data from mHealth apps can be used to produce quality
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31 improvement, specifically in relation to nursing. This review also highlights a need
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33 for the development of apps that aim to capture data to inform quality
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35 improvement, particularly from the patient perspective.
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42 **Keywords:** mHealth, app, data (or data collection), quality improvement,
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44 healthcare, integrative review
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BACKGROUND

The ubiquitous nature of mobile phones and other portable information technology (IT) devices has seen the rapid development and acceptance of mobile health (mHealth) application (app) use in healthcare. The World Health Organisation (WHO) acknowledge that there is no global consensus on the definition of mHealth and offer a definition of mHealth as “medical and public health practice supported by mobile devices, personal digital assistants (PDA’s) and other wireless devices” (WHO, 2011, p. 6). Informed by this definition, this review defines mHealth as ‘the use of mobile technologies to support health information, medical practices and the achievement of health objectives’.

As a number of definitions of quality improvement in healthcare exist it is essential to also outline how quality improvement is defined in this review. This review draws its definition of quality improvement from the globally recognised Institute for Healthcare Improvement (IHI). The IHI definition/understanding of quality improvement stems from the science of improvement approach. This approach views quality improvement as “an applied science that emphasizes innovation, rapid-cycle testing in the field, and spread in order to generate learning about what changes, in which contexts, produce improvements. It is characterized by the combination of expert subject knowledge with improvement methods and tools. It is multidisciplinary — drawing on clinical science, systems theory, psychology, statistics, and other fields” (reprinted from www.IHI.org with permission of the Institute of Healthcare Improvement (IHI), ©2018). This definition of quality

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3 improvement in healthcare is relevant to healthcare clinicians at all levels of practice
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5 from management to clinical care. However, the focus of this article is on those
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7 involved in direct clinical care.
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12 In clinical practice, mHealth apps can be used to assist in delivering effective patient
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14 care, facilitate research and inform quality improvement by examining data about
15
16 both illness management and patient experience. Use of mHealth applications in
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18 healthcare deliver several benefits over traditional methods by providing
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20 convenient, real-time, portable access to health information services and enabling
21
22 the collection and storage of large amounts of data(World Health Organization
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24 (WHO), 2016). [Historically, data has been fundamental in supporting and informing](#)
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26 [change in healthcare. This capacity to support healthcare and collect data results in](#)
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28 [mHealth apps holding great potential to play a pivotal role in health care delivery](#)
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30 [and quality improvement.](#)
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37 mHealth apps have been developed to collect and deliver health related information
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39 for both patients and clinicians for a variety of purposes including (but not limited
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41 to): communication, patient management, medication compliance, diagnostic tools,
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43 education, behavioural prompts, reminder purposes, self-management, post-op
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45 care, personal health records, and reference information. There are large amounts
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47 of evidence available relating to the development and implementation of such apps.
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49 [However, despite the sizeable number of apps available for both healthcare](#)
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51 [providers and patients, there is limited evidence available on how the data](#)
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3 generated from these apps is used, particularly in relation to using that data to
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5 inform quality improvement.
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9 10 **AIM**

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12 As outlined above, data collected from mHealth apps holds potential to be used to
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14 inform sustainable quality improvement in healthcare. As such, the aim of this
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16 integrative review is to establish current knowledge of how mHealth apps are used
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18 to produce data to inform quality improvement in practice.
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23 24 **METHOD**

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26 This integrative review was performed in accordance with guidelines for integrative
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28 reviews by Whittmore & Knafel (2005) and Hopia, Latvala & Liimatainen (2016).
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33 34 **Search Strategy**

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36 In October 2017, a comprehensive search of the Scopus, Web of Science, CINAHL
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38 and MEDLINE Plus Full Text databases was performed (see Figure i) to identify
39
40 current evidence suitable to answer the PICO question 'how are apps used to
41
42 produce data in healthcare to inform quality improvement?
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47 Key words used in the search strategy included apps OR app OR "mobile
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49 application", healthcare OR "healthcare" OR hospital OR nursing OR "quality
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51 improvement" OR "quality*" OR "practice improvement". Each search string was
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53 combined with the boolean operator AND to obtain focused results. Each search
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55 string was searched in both title and topic to ensure comprehensive coverage of the
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3 topic of interest and was altered to search each database's individual requirements.
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5 Full details of the electronic search strategy used in the Web of Science database can
6
7 be seen in Table 1.
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11 **Study Selection and Data Extraction**

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14 One reviewer independently evaluated the search results based on an agreed
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16 inclusion criteria of a) full text, b) empirical research studies, c) relating to mobile
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18 health application use (not development) d) in clinical care. Excluded from the
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20 review were research protocols, manuscripts, editorials, conference papers and non-
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22 English publications, apps that provided education/information and didn't collect
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24 data, or papers on app development. Data was then extracted from the 19 studies
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26 that met the inclusion criteria and collated in an electronic table (Table 2). This
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28 process and its results were then critiqued by the other investigators.
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35 **Quality Assessment**

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37 To assess the validity of the results and relevance of the studies identified, quality
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39 assessment of the articles included in the review was completed using the Critical
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41 Appraisal Skills Programme (CASP) checklists for critical appraisal of qualitative
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43 research (CASP, 2017), randomised controlled trials (CASP, 2017a) and systematic
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45 review (CASP, 2017b). These tools were selected, as they are well-recognised tools in
46
47 critical appraisal of research and provide a variety of checklists to systematically
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49 assess the varying study designs found in the research studies included. Risk of bias
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51 within the studies was assessed using The Cochrane Risk of Bias Tool (Higgins et al.,
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53 2011).
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RESULTS

The search strategy yielded a total of 710 articles from across all four databases, which reduced to 634 once duplicate articles were removed. It is important to note that CINAHL and Medline Plus Full Text yielded many results for each individual search string, however when combined with 'AND' nil results were obtained. The 634 articles identified from the database searches were screened by title and abstract and 563 records were excluded based on the inclusion/exclusion criteria (of which a large number were research protocols). The 71 remaining articles identified were then located in full text and reviewed in more depth to assess for eligibility. Further screening of the reference lists of these articles also identified 4 additional articles. After reviewing these articles in relation to the exclusion criteria, a total of 56 articles were excluded and 19 articles were selected for evidence synthesis.

Study Characteristics

The years of studies yielded in the initial database searches spanned from 1991-2017. However, the articles that met the inclusion criteria for evidence synthesis spanned from 2012-2017 indicating the emergence and developing nature of this topic in healthcare over the last five years. Studies were conducted in 17 different countries including seven in the United States of America, four in Canada, two in the United Kingdom, Sweden, China and Korea, and one in Turkey, New Zealand, Germany, India, Iran, Japan, Democratic Republic of Congo, Spain, Czech Republic, Italy, and Australia. One study reported by Holmen, Wahl, Smastuen & Ribu (2017) was conducted across three countries.

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5 Studies varied greatly in their aims, methodologies and sample sizes. A variety of
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7 study designs were selected for analysis, including 4 systematic reviews (Holmen et
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9 al., 2017; Kitsiou, Pare, Jaana & Gerber, 2017; Lee et al., 2015; Peiris, Praveen,
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11 Johnson & Mogulluru, 2014), 4 randomised control trials (Armstrong, Coyte, Brown,
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13 Beber & Semple, 2017; Cingi et al., 2015; Lakshminarayana et al., 2017; Wolf et al.,
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15 2016), 1 non-randomised control trial (Sundberg et al., 2017), 3 retrospective cohort
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17 studies (Dickson, Sumathipala & Reeves, 2016; Khanna, Sambandam, Gul &
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19 Mounasamy, 2015; Twichell et al., 2017), 6 pilot studies (Foo et al., 2015; Gunter et
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21 al., 2016; Jakel et al., 2016; Macpherson et al., 2014; Patel, Siegler, Stromberg, Ravitz
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23 & Hanson, 2016; Semple, Sharpe, Murnaghan, Theodoropoulos & Metcalfe 2015)
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25 and 1 case report (Gernart et al., 2017).
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33 **Populations of Interest**

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35 Eleven out of the nineteen studies reviewed involved patients and medical clinicians
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37 and three involved medical clinicians alone (with 3/19 studies not specifying
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39 population of interest for the apps). Only two studies involved nursing staff (Jakel et
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41 al., 2016; Patel et al., 2016). The aim of the study by Jakel et al (2016) was to
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43 examine if use of a Provider Resilience mobile application would improve
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45 professional quality of life for a cohort of oncology nurses. This app collected data to
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47 evaluate healthcare providers level of compassion fatigue, burnout and compassion
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49 satisfaction, however, the results of using the application were not statistically
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51 significant. The aim of the study by Patel et al (2016) was to evaluate the impact of
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53 using a smartphone-based communication app to improve communication between
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3 healthcare clinicians including clinical teams, doctors, nurses, social workers,
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5 pharmacists and secretaries. The outcome of this study was that nurses and doctors
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7 both reported texting on a smart device was more efficient and less disruptive than
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9 making phone calls or using pagers with statistical significance of <0.0001 in
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11 responses relating to efficiency and workflow.
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16 All studies selected involved mHealth apps used in a hospital/clinical care context.
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18 The predominant population of interest were patients (8 adult and 1 paediatric) with
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20 two studies looking at both adult and paediatric patients (Lee et al., 2015;
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22 Macpherson et al., 2014) and three studies not explicitly stating the age of the
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24 population impacted by the app (Cingi et al., 2015; Dickson et al., 2016; Lee et al.,
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26 2015). Five studies reviewed apps relating to healthcare clinicians including medical,
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28 nursing, social work, pharmacists, and clerical staff (Foo et al., 2015; Jakel et al.,
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30 2016; Khanna et al., 2015; Lee et al., 2015; Patel et al., 2016).
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37 **Functions of Apps**

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39 The functions of the apps outlined in the studies were discussed and themed by the
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41 authors until consensus was reached on four different categories ; communication,
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43 illness management, clinical management and education/information. Despite the
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45 different functions, data from all mHealth apps provided support whether that was
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47 relating to the patient experience, decision-making or treatment delivery. See Table
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49 3 for a detailed breakdown of app functions.
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Data Collected Using mHealth Apps

The types of data collected by the apps included numerical data e.g. numbers, survey scores, vital signs (Cingi et al., 2015; Dickson et al., 2016; Foo et al., 2015; Gernart et al., 2017; Jakel et al., 2016; Sundberg et al., 2017), textual data e.g. using words, phrases or more in depth descriptions (Cingi et al., 2015; Gernart et al., 2017), photographic data e.g. photos of wounds (Khanna et al., 2015; Semple et al., 2015), graphic data where graphs or scales were generated as a result of patient/physician input or where images were selected by users to express symptoms (Foo et al., 2015), with a number of apps able to collect a variety of data types.

As well as the ability to collect an assortment of data types, the apps reviewed were at times able to collect large amounts of data, for example a study on communication (Patel et al., 2016) reviewed 708, 456 text messages whilst another looked at over 6800 abnormal blood pressure measurements (Twichell et al., 2017). There was also considerable variance in study participants ranging from eight orthopaedic residents in a study about the use of smart phone technology in India (Gunter et al., 2016) to over 1450 in a communication study (Patel et al., 2016).

Data collected through apps was used both in real-time to deliver healthcare, inform healthcare decision-making and create self-awareness (Armstrong et al., 2017; Cingi et al., 2015; Dickson et al., 2016; Foo et al., 2015; Gunter et al., 2016; Jakel et al., 2016; Khanna et al., 2015; Macpherson et al., 2014; Semple et al., 2015; Sundberg et

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3 al., 2017; Twichell et al., 2017), and retrospectively to inform healthcare
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5 management (Gernart et al., 2017; Lakshminarayana et al., 2017; Semple et al.,
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7 2015; Wolf et al., 2016), communication strategies (Khanna et al., 2015; Patel et al.,
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9 2016) and healthcare delivery changes (Foo et al., 2015).
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14 **Quality Improvements as a Result of mHealth App Use**

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16 Whilst not the main focus of the apps, a number of quality improvements and
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18 outcomes were reported in the studies reviewed. These included improvements to:
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20 clinical outcomes (Cingi et al., 2015), disease control and management (Kitsiou et al.,
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22 2017; Lakshminarayana et al., 2017), quality of life (Cingi et al., 2015; Sundberg et al.,
23
24 2017), time to treatment (Dickson et al., 2016; Twichell et al., 2017), communication
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26 (Foo et al., 2015; Khanna et al., 2015; Macpherson et al., 2014), awareness of patient
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28 information (Khanna et al., 2015; Lee et al., 2015), symptom burden (Sundberg et al.,
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30 2017), emotional functioning (Sundberg et al., 2017), medication adherence
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32 (Lakshminarayana et al., 2017), time efficiency (Foo et al., 2015; Khanna et al., 2015;
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34 Lee et al., 2015; Patel et al., 2016; Semple et al., 2015), disease management
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36 (Holmen et al., 2017), follow up time (Armstrong et al., 2017; Semple et al., 2015)
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38 and patient management (Foo et al., 2015; Lakshminarayana et al., 2017). Of the
39
40 nineteen studies reviewed, only one article (Foo et al., 2015) made explicit links
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42 outlining that data collected from the app was used to inform quality improvement.
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44 The quality improvements outlined by the other eighteen studies were related
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46 directly to using the app itself with some articles indicating the potential for future
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48 quality improvement based on study results.
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DISCUSSION

The findings of this review confirm the global interest and potential international impact of mHealth applications to assist in both the delivery and development of healthcare with seventeen countries being represented in the nineteen studies reviewed. As can be seen from the year of publication of included studies (2012-2017), the use of mHealth apps to produce data that informs quality improvement is an emerging area in healthcare. This is congruent with the findings from Peiris et al (2014) who found a large number of grey literature outlining studies in progress or randomised control trials with findings yet to be reported. This is further reflected in the findings of this review where twelve out of the fifty-six articles excluded were relating to mHealth app development (see Figure i).

It was interesting to note that only two out of nineteen studies involved nursing staff (of which only one had statistically significant results), compared to fifteen involving medical staff. [This finding highlights the limited evidence available and subsequent need for further research relating to data collection through mHealth apps in the discipline of nursing.](#) This finding is congruent with Foo et al.(2015), who outlined that further research focussing on nursing teams in relation to the use of mHealth apps used to track patient journey and clinical task management is key to improving the functionality of current apps. [The findings of this review also confirm this as the functions of the apps used by nursing staff in this review were relating to education/information and communication not illness or clinical management.](#) [Nurses are an integral part of the healthcare team and play a significant role in the delivery of front line patient care. This proximity to patients places them in a key](#)

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3 position for collection of data that could be used to inform quality improvement,
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5 particularly in relation to clinical or illness management.
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10 As mentioned above, the four types of data collected by the mHealth apps in the
11 articles reviewed included numerical, textual, imaged or graphical data with
12 numerical and textual data being the most common form of data collected.
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15 However, whilst data collection was possible from all the apps utilised in the studies,
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17 review of these studies revealed that data collection was often not the purpose of
18
19 the apps themselves. The main functions of the apps were to improve
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21 communication, illness and clinical management and provide education/information.
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24 Although the purpose of the apps was improvement focussed, it was the data
25
26 collected by the mHealth apps that informed these changes. The data from these
27
28 apps was used for a variety of purposes resulting in quality improvement e.g. faster
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30 identification of changes in patient condition (Semple et al., 2015; Twichell et al.,
31
32 2017), improving communication processes (Foo et al., 2015; Khanna et al., 2015;
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34 Patel et al., 2016), enhancing understanding of quality of life (Cingi et al., 2015;
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36 Lakshminarayana et al., 2017; Sundberg et al., 2017), increasing patient compliance
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38 (Cingi et al., 2015; Gernart et al., 2017; Kitsiou et al., 2017; Wolf et al., 2016) and
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40 improving access to and satisfaction with healthcare (Dickson et al., 2016;
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42 Lakshminarayana et al., 2017).
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51 This review outlines that data is collected through mHealth apps both in real-time
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53 and retrospectively, with benefits to both approaches. Benefits of utilising real-time
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55 data include (but are not limited to) timely interventions and decision-making
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3 relating to clinical care and illness management and improved accuracy of
4
5 information collected. The increasing accessibility and portable nature of mHealth
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7 devices enables the data collection process to be more efficient and effective due to
8
9 shorter time spent collecting and collating data when using a mHealth app. It also
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11 provides greater access for patients to be involved in data collection from the
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13 convenience of their hospital beds or homes. Having data stored in an app rather
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15 than paper, and [having it accessible in real time also improves the time taken for](#)
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17 [clinicians/researchers to access this data and make appropriate data-informed](#)
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19 [changes to practice](#). Using an app to collect data in real-time reduces the risk of
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21 missing data sets; as it is all stored in a central online, secure space and cannot be
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23 misplaced after collection. [Collecting and using data from mHealth apps](#)
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25 [retrospectively also equips clinicians with information on healthcare processes over](#)
26
27 [time, which can be used to inform sustainable healthcare change and provide](#)
28
29 [evidence for both clinicians and patients](#) e.g. reviewing effectiveness of interventions
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31 (Khanna et al., 2015; Patel et al., 2016), patient treatment compliance via mHealth
32
33 app diaries (Gernart et al., 2017; Wolf et al., 2016), understanding quality of life
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35 (Cingi et al., 2015; Gernart et al., 2017; Wolf et al., 2016), reviewing time to
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37 treatment (Dickson et al., 2016) and using data captured on the app as a memory aid
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39 when attending follow up appointments (Lakshminarayana et al., 2017).
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49 The most common focus of data collection related to communication and illness
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51 management. Collection of data from the patient perspective in relation to the care
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53 experience provides key information on the quality of care and its effect on the
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55 patient (McCance, Wilson & Kornman 2016). This data provides a platform for the
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3 delivery of person-centred care, identification of gaps in care delivery and quality
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5 improvement. However only five out of nineteen studies used mHealth apps to
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7 explore the patients experience in healthcare and the impact of illness on quality of
8
9 life (Cingi et al., 2015; Gernart et al., 2017; Lakshminarayana et al., 2017;
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11 Macpherson et al., 2014; Sundberg et al., 2017). These studies predominantly
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13 provided data for the medical clinician/s caring for these patients with only two
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15 studies mentioning providing this information to nurses. This indicates the need for
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17 further research where data collected from mHealth apps is provided to healthcare
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19 clinicians, in particular, nursing staff.
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26 This review highlights that data from mHealth apps is used for the benefit of both
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28 patients and clinicians in healthcare. For patients this includes recognition of
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30 abnormal results (Semple et al., 2015; Twichell et al., 2017), improved illness
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32 management (Cingi et al., 2015; Kitsiou et al., 2017; Lakshminarayana et al., 2017;
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34 Peiris et al., 2014; Semple et al., 2015; Wolf et al., 2016), improved accuracy of
35
36 electronic health records and health data (Lakshminarayana et al., 2017; Wolf et al.,
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38 2016), real time communication and feedback (Peiris et al., 2014; Sundberg et al.,
39
40 2017), faster treatment time (Armstrong et al., 2017; Dickson et al., 2016; Semple et
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42 al., 2015), enhanced patient experience (Armstrong et al., 2017; Lakshminarayana et
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44 al., 2017; Semple et al., 2015; Sundberg et al., 2017), access to health and health
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46 system information (Lakshminarayana et al., 2017; Lee et al., 2015), and self-
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48 awareness and education (Holmen et al., 2017; Kitsiou et al., 2017; Lakshminarayana
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50 et al., 2017). For healthcare providers (predominantly medical), this includes the
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52 improvement of communication between healthcare teams (Foo et al., 2015;
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3 Khanna et al., 2015), improvement of patient management pathways (Dickson et al.,
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5 2016; Foo et al., 2015; Twichell et al., 2017), time and cost efficient healthcare
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7 delivery (Gunter et al., 2016; Lee et al., 2015; Semple et al., 2015), greater
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9 understanding of patient compliance (Kitsiou et al., 2017; Lakshminarayana et al.,
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11 2017; Wolf et al., 2016) and the impact of work and illness on emotional well-being
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13 and quality of life (Gernart et al., 2017; Jakel et al., 2016; Lakshminarayana et al.,
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15 2017; Macpherson et al., 2014).

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21 Whilst the studies reviewed attributed several benefits from utilising mHealth apps,
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23 it was interesting to note that only one study's focus was the collection of data
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25 through an mHealth app for the purpose of informing quality improvement (Foo et
26
27 al., 2015). This indicates that the use of mHealth apps to produce data to inform
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29 quality improvement is more of an innate outcome rather than an explicit focus
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31 within healthcare, highlighting the need for further research and development in this
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33 area.
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40 **Limitations**

41
42 The limitations of this review include having a single reviewer screen and appraise
43
44 the articles selected, under guidance from supervisors. While every effort was made
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46 to retrieve all relevant articles as a result of a rigorous search strategy, it is
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48 acknowledged that this search was undertaken at a point in time in what is a rapidly
49
50 evolving field.
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55 **IMPLICATIONS FOR FUTURE RESEARCH**

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3 This review highlights how data obtained from mHealth apps can and is being used
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5 to inform quality improvement in healthcare. The emerging nature of this topic
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7 evidenced by the recent studies published and low number of high quality evidence
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9 of studies available, indicate that further research is required in this area to
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11 adequately understand how data from mHealth apps can and is being used to
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13 produce quality improvement, specifically in relation to nursing. This review also
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15 highlights a need for the evaluation of data produced by existing mHealth apps and
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17 the development of apps that specifically aim to capture data to inform quality
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19 improvement, particularly from the patient perspective.
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25 26 **CONCLUSIONS**

27
28 In conclusion, this review highlights the emerging nature of using data collected
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30 from mHealth apps to inform quality improvement in healthcare. Analysis of the
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32 included studies showed that although data collection is rarely outlined as the
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34 explicit purpose of mHealth apps, when collected through such technology, is used
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36 to inform practice change both in real-time and retrospectively. These
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38 improvements include benefits for both patients and clinicians such as improved
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40 disease control and management, quality of life, communication and time efficiency.
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3 This work was supported by the Australian Federal Government Research Training
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5 Program Scholarship.
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14 **LINKING EVIDENCE TO ACTION**

- 17 • Data from mHealth apps can be used to inform improvements for both
18 patients and clinicians such as improved disease control and management,
19 quality of life, communication and time efficiency.
- 20 • Evaluation and use of data from existing mHealth apps used in practice to
21 inform quality improvement is needed.
- 22 • Further research is required to adequately understand how data from
23 mHealth apps can be used to produce quality improvement, specifically in
24 relation to nursing.
- 25 • This review also highlights a need for the development of apps that aim to
26 capture data to inform quality improvement, particularly from the patient
27 perspective.
- 28 • There is a need for increased publication of high quality evidence relating to
29 data collection through mHealth apps used in nursing, particularly from
30 countries in the Southern Hemisphere.
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Figure i) Literature search flow diagram

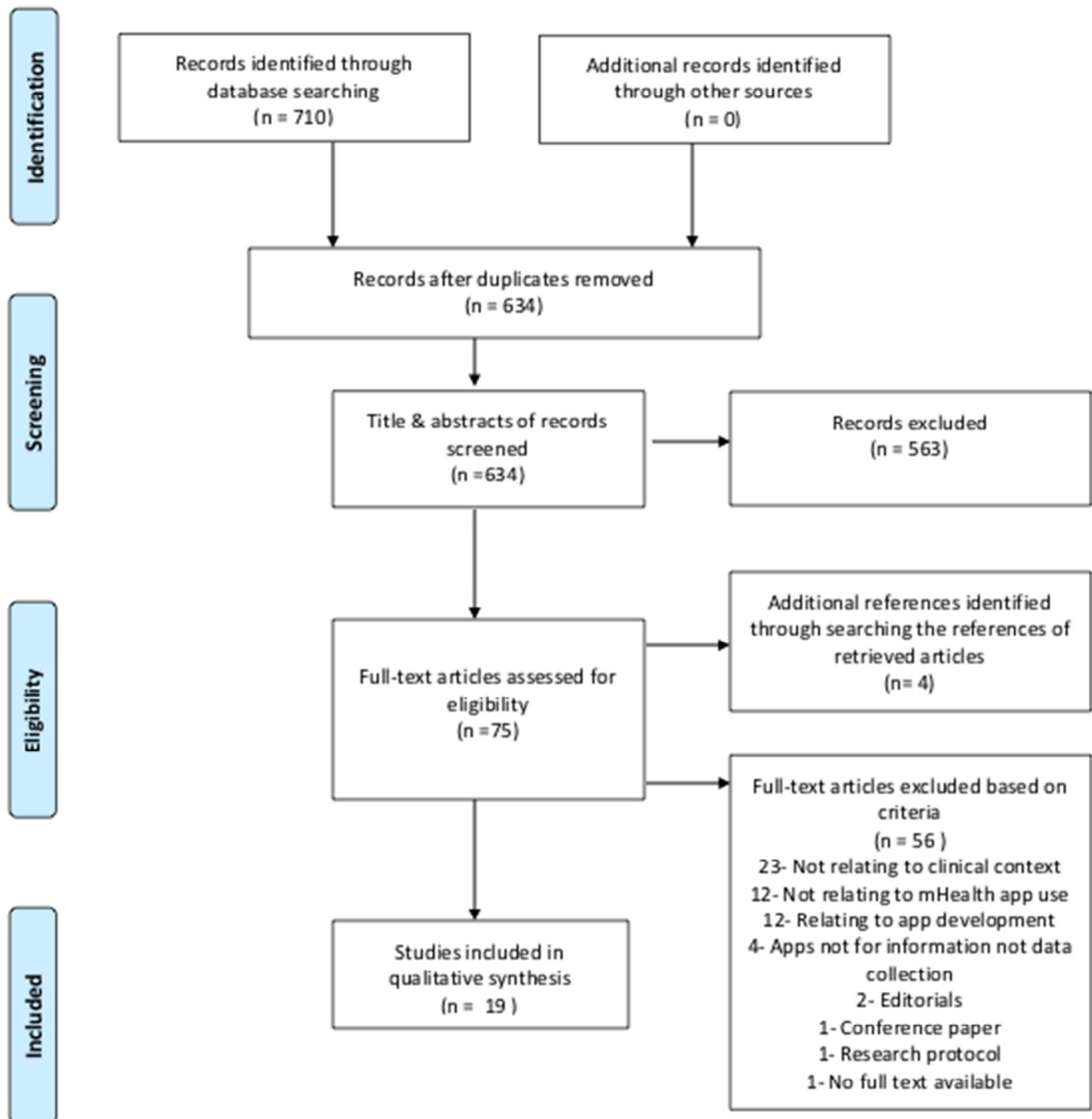


Table 1. Web of Science Search strategy

#1	TOPIC apps OR app OR "mobile application"
#2	TITLE apps OR app OR "mobile application"
#3	TOPIC healthcare OR "healthcare" OR hospital OR nursing
#4	TITLE healthcare OR "healthcare" OR hospital OR nursing
#5	TOPIC "quality improvement" OR "quality*" OR "practice improvement"
#6	TITLE "quality improvement" OR "quality*" OR "practice improvement"
#7	#1 OR #2
#8	#3 OR #4
#9	#5 OR #6
#10	#7 AND #8 AND #9
#11	Refine to ENGLISH + ARTICLE OR REVIEW
#12	Refine to EXCLUDE non-health/medicine

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For Peer Review

Table 2. Characteristics of included studies.

Author & Year	Country	Population	Study Aim	Study Design	App name & function	Data Collected	Results/Quality Improvement
Armstrong et al., 2017	Canada	Ambulatory adult patients undergoing breast reconstruction	To determine whether follow up-care delivered via a mobile app can be used to avert in-person follow-up care visits compared with conventional, in person follow-up care in the first 30 days post ambulatory surgery	Randomised control trial Sixty-five participants	QoC Health Inc Mobile App Allows patients to: - submit photographs, answer a validated quality of recovery questionnaire and a pain visual analogue scale using a mobile device for the first 30 days after the operation Surgeons can follow patient reports on a web portal	Textual Image	Participants using the app reported greater level of convenience in follow up care compared to in-person group minimal difference between satisfaction scores between app group vs in-person group neither satisfaction or convenience scores were statistically significant
Cingi et al., 2015	Turkey	Patients with allergic rhinitis and asthma (no age group specified)	Impact of mobile patient engagement app on health outcomes and quality of life	Randomized control trial Three hundred and seventy-five participants	POPET (Physician On-Call Patient Engagement Trial) Communication, health management, medication compliance	Numerical Textual	Improved quality of life and clinical outcomes. Rhinitis group Clinical improvement, improvement in rhinitis quality of life, activity (statistical significance p=0.05) Asthma group improved number of well controlled asthma score
Dickson, Sumathipala & Reeves, 2016	United States of America	Patients with Acute Ischaemic Stroke (AIS) (no age specified)	Evaluate effect of app on door-to-needle (DTN) time in patients presenting to Emergency Departments with AIS	Retrospective cohort study Eighty-five activations over 18-month period	Pulsara StopStroke Medical app aimed at enhancing rapid assessment and care of patients suffering from AIS	Numerical	App use resulted in reduction in door-to-needle time by 46% (p=0.001)

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7	Foo et al., 2015	New Zealand	Healthcare clinicians (consultants, junior doctors & house officers)	Assess impact of mobile task management tool on clinical workflow within an acute general surgical service	Pilot study Sixteen staff members (where 14/16 completed usability survey)	Cortex – mobile iOS task management application - provides the clinical team with digitization of the patient journey, synchronous with decision-making and clinical task performance	Numerical Graphical	Faster decision making reduced redundancy of work improved team communication capture of data re: patient journey and workflow which was not previously available
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15	Gernart et al., 2017	Germany	Adult patients with chronic pruritus	To validate ItchApp as a novel instrument	Validation study and Randomised, double-blind placebo-controlled trial using the app Forty participants	ItchApp – E-diary for use in clinical trials to generate increased reliability of prospective data Obtains data on: itch intensity questionnaires, quality of life	Numerical and textual	-94% level of patient compliance -data from app easily managed and analysed -simplified data collection process
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23	Gunter et al., 2016	United States of America	Adult patients >18 years in the vascular or general surgery service of a large tertiary hospital	1) develop a novel image-based smartphone app for post discharge surgical wound monitoring 2) rigorously user test it with a representative population of vascular and general surgery patients	Descriptive study Nine participants	Woundcheck an iOS app that enables patients to capture digital images of surgical wounds and sends them to their provider from home along with brief updates of post op recovery Includes 2 phases 1- image taking phase 2- brief survey with 6 yes or no questions re: recovery	Imaged Textual	Above average overall usability score 83.3 At the time of publication first app to add asynchronous visual component to outpatient monitoring apps. Testing allowed for change to be made to the app and identify gaps in education support for patients using app.
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36	Holmen et al., 2017	Studies from Japan	Patients >16 years with	Systematically review studies that aimed to	Systematic literature review	Majority of apps focusing on	Numerical Textual	Unclear methodological quality of studies,
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	China Korea Democratic Republic of Congo Canada and 1 multicentre study in Italy, Spain and Czech Republic	diabetes (type 1 and type 2)	evaluate integrated communication within mobile apps for tailored feedback between patients with diabetes and health care personnel in terms of study characteristics, functions, study outcomes, effects and methodological quality		communication e.g. SMS interaction, reminders, texting of blood glucose levels, feedback from health care professional and therapeutic advice. Small number of apps transmitting blood glucose level and dietary intake. Others relating to self-management & education,		implications for need for more controlled trials of higher methodological quality Outcome measures of app related to disease management but did not mention outcomes relating to quality improvement 1/6 measured therapy satisfaction
Jakel et al., 2016	United States of America	Adult oncology nurses	Examine if the use of the app will improve oncology nurses' professional quality of life	Prospective quasi-experimental pilot study 25 participants	PRMA (Provider Resilience Mobile Application) tool to increase provider resilience. It includes psychoeducation, methods to evaluate level of burnout, compassion fatigue, compassion satisfaction and secondary trauma stress using a visual analogue scale, questionnaire, and r&r clock to remind participants time since the user took a day off	Numerical Textual Graphic	No change seen in the pre- and post-test scores of the intervention group, control group or sample as a whole
Khanna, Sambandam, Gul & Mounasamy 2015	India	Adult clinicians (8 orthopaedic residents)	Report the impact of the introduction of a smartphone application as an intradepartmental	Retrospective study Eight residents	WhatsApp – cross platform mobile messaging app allowing the exchange of	Textual images numerical	High scores indicating improved awareness of patient information statistically significant (p=

			communication tool on 1) awareness of patient related information 2) efficiency of handover process 3) duration of traditional morning handovers among orthopaedic residents	participated Total 50 admissions reviewed (25 pre-WhatsApp 25 post WhatsApp)	messages and media over the internet		0.019). All residents found WhatsApp helpful in improving the efficiency of handovers and standard of patient care. Statistically significant reduction in the time of written handovers in the morning from 25minutes to 14 minutes (p=0.003)
Kitsiou et al., 2017	United States of America United Kingdom China Canada Iran	Patients with type 1 and type 2 diabetes	Purpose of the overview is to critically appraise and consolidate evidence from multiple systematic reviews on the effectiveness of mHealth interventions for patients with diabetes to inform policy makers, practitioners and researchers	Systematic review	Majority of apps focusing on communication e.g. SMS interaction, reminders, texting of blood glucose levels, feedback from health care professional and therapeutic advice. Small number of apps transmitting blood glucose level and dietary intake Others relating to self-management & education,	Textual Numerical	On average mhealth interventions reviewed improved glycaemic control compared to standard care of other non mhealth approaches as much as 0.8% for patients with type 2 diabetes and 0.3% for patients with type 1 diabetes. Large variability in quality of studies reviewed
Lakshminarayana et al., 2017	United Kingdom	Patients with Parkinson's Disease 68 patients in PTA group and 90 in TAU group	To assess if patients with Parkinson's disease who use a Parkinson's tracker app (PTA) for 16 weeks in addition to treatment as usual (TAU) show improved self-reported	Randomized control trial One hundred and fifty-eight participants	Parkinson's tracker app -Sliding petal interface to track 10 self-monitoring measures on a 5-point scale (sleep, exercise, mood, energy, movement suppleness) -Reminder system for	Numerical Textual	Statistically significant result indicating use of app to produce quality improvement for patients with Parkinson's disease over 16-week period. -Improved patients' perception of quality of

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			medication adherence. Secondary objectives were to investigate whether patients who receive the PTA and those who receive TAU differ in terms of quality of life, quality of clinical consultation and symptom control		patients to set up for alerts to track medication -Option to generated a report of data entered by the patient over the trial period as an aid at their 16 week follow up appointment -Games to track physical responsiveness -Information about Parkinson's disease		consultation (p=0.0110) -Improved medication adherence compared to treatment as usual (p=0.0304)
Lee et al., 2015	Korea	Not specified Apps for both adult and paediatric patients & healthcare clinicians	To evaluate the mobile health applications with focus on quality and patient safety developed by a single tertiary hospital in Korea	Evaluation/ Systematic Review of twenty three studies in Korea . Apps evaluated re: 6 aims for quality improvement suggested by US Institute of Medicine (patient centredness, effectiveness, patient safety, timeliness, efficiency, equity)	23 different apps PATIENTS -my medications -my chart in my hand -pharm consult -wild plants in Korea -pediatric cancer diary -injini -quality of life -my cancer diary -pediatric cancer information -pit-a-pat BOTH -emergency in ordinary life HEALTHCARE PROVIDERS -ASAN phonebook -CPCR drugs -toxicology -mAMIS	Textual numerical Several apps provided information rather than collect data 8/23 apps	Apps designed between 2010-2014 - Only 2 apps met all 6 aims for quality improvement -Most of the apps designed for patients provide health information or patient medical information (7/10 apps) -1 app for patients collected survey data -4/23 apps were personal health record -3/13 healthcare provider apps focussed on communication

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Macpherson et al., 2014	United States of America	72 adolescents and young adults 13-29 years of age with cancer. at 5 institutions across the USA	Aim of the study was to evaluate the feasibility and acceptability of a computer based symptom cluster heuristics tool designed to explore symptom clusters experienced by adolescents and young adults with cancer	Feasibility study Seventy-two participants	Computerized symptom capture tool (C-SCAT) Features 30 symptoms commonly experienced by adolescents and young adults with cancer, combines graphical images and free text responses in an innovative heuristics approach to gain the perspectives of AYA's on their symptoms and symptom clusters Allows participants to drag and drop the symptoms experienced in the last 24hours	Textual Graphical Images	All 72 participants completed the C-SCAT with 74% of participants reported that the final image was an accurate or very accurate representation of their symptom experience C-SCAT demonstrated feasibility and acceptability app has potential to empower adolescents and young adults to 1) communicate symptom experience and partner with providers in their care 2) improve symptom management and ameliorate distress 3) translate to use with other highly symptomatic populations
Patel et al., 2016	United States of America	Healthcare clinicians (clinical teams, doctors, nurses, social	To determine if a commercially available smartphone based secured messaging	Pre-post evaluation study Text messages	Cureatr- Health Insurance Portability and Accountability Act (HIPAA)-complaint	Textual Numerical	Different number of respondents in pre-and post evaluation study and inability to link responses

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		work, pharmacists, secretaries) 1 surgical and 3 general medical units	application has the potential to allow providers to communicate efficiently and effectively as a care team.	were analysed to evaluate utilization, pattern and adoption of the communication solution 1021 providers involved sent 708, 456 messages One hundred and thirty-six nurses and ninety-three physicians completed pre-survey One hundred and twenty-seven nurses and eighty-three physicians completed post survey	messaging application Used for the transmission of encrypted text messages via hospital wireless network		from first and second survey made interpretation of results difficult. Large number of group messages 1/6 messages indicating that use of the app facilitates virtual team conversations Nurses and residents reported that texting on smart devices was more efficient and less disruptive than using phone calls or pagers Further research required to determine impact on patient outcomes and confirm effectiveness and safety of messaging solution
Peiris et al 2014	Conducted in Australia	Adults (patients and volunteers) with non-communicable diseases (cardiovascular disease, diabetes, cancer,	Asses the impact of mHealth interventions on health care quality. Characterise the spectrum of mobile health interventions that have been used for non-	Systematic Literature Review	48 studies across Brazil, Turkey, China, Honduras, India, Malaysia, Cameroon, Thailand, Iran, Argentina & Mexico. Apps focussed on:	Textual Numerical	mHealth for non-communicable diseases is under-explored, however several study protocols indicating future growth in this area. Despite mHealth having a

		respiratory disease) in low- and middle-income countries	communicable disease management and prevention in low and middle- income countries		<ul style="list-style-type: none"> -Sensors and point of care diagnostics -communication -Decision support -Client education -Telecare intervention -Disease management - SMS reminder system -interactive voice system -disease monitoring -electronic health record -medication adherence -data collection 		<p>wide variety of applications, studies so far are dominated by behaviour change interventions through use of text messaging systems. Few studies have applied mHealth tools as a means of strengthening health systems/quality improvement. No studies looked at equity or safety issues</p>
19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37	Canada	Ambulatory care patients undergoing breast reconstruction or orthopaedic arthroscopic anterior cruciate ligament repair	To assess the feasibility of using a mobile app for the monitoring or post-operative quality of recovery at home following surgery in an ambulatory setting	<p>Prospective cohort study (pilot study)</p> <p>Sixty-five surgical participants (Thirty-three breast reconstruction and thirty-two orthopaedic surgery)</p>	<p>App name not outlined.</p> <ul style="list-style-type: none"> -Using photographic data of wound uploaded daily -visual analogue scale for pain and likert questions from the quality of recovery questionnaire (QoR-9) <p>App would alert surgeon if 'flag' value identified from patient data input & would also place the patient on top of the surgeons list and highlight them as red on surgeons' dashboard the surgeon could then call the patient and enquire re: the high score, app updated</p>	Imaged	<p>Effective Mobile app monitoring is feasible and acceptable to both patients and surgeons</p> <p>Patient satisfaction very high 3.9/4 satisfaction score</p> <p>2 potential post op complications identified prior to scheduled follow up resulting in better patient outcome due to faster time of identification.</p> <p>Cost and time effective benefit also highlighted by surgeons.</p>

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7	Sundberg et al., 2017	Sweden	Male patients mean age 69 years with prostate cancer	Evaluate the effect on symptom burden and quality of life when using the application for real- time symptom assessment and management during radiotherapy for localised prostate cancer	Non-randomized control trial One hundred and thirty participants Sixty-four participants in control group Sixty-six participants in intervention group	Interaktor An app for smartphones and tablets for early detection, reporting and management of symptoms and concerns during treatment for prostate cancer. Allows real time communication and rapid management of symptoms when detected early	Textual and numerical Reporting symptoms via the application had positive effect on symptom burden and quality of life Statistically significant results for intervention group in emotional functioning Control group also had statistically significant lower levels of quality of life
19	Twichell et al., 2017	United States of America	Paediatric patients 3-18 years of age with one BP above the 90 th age-sex-height referenced percentile	Examine change in abnormal blood pressure recognition before vs. after the introduction of an electronic health record app designed to calculate BP percentiles with a training lecture	Retrospective cohort study 78, 768 clinical encounters reviewed. Three thousand five hundred and twenty-one had abnormal BP's pre-app use Three thousand, three hundred and fifty-eight had abnormal BP's post app use	Substitutable Medical Applications & Reusable Technology (SMART) BP Centiles App Free, substitutable, open-source, open access BP calculator and longitudinal tracking tool capable of running within any Electronic Health Record that supports the SMART Health IT Platform. The app displays the BP percentile with an ambulatory blood pressure measurement, as well as historic blood pressure percentiles allowing providers to determine if an elevated	Numerical Graphical As app use was voluntary and not mandated or included in workflow, it was only used in 13% of clinical encounters when the BP was elevated, = 5% use in overall clinical encounters = small sample. Despite small sample size app use was associated with significantly higher recognition of abnormal BP 4.9% pre-app and 7.1% post app (p=0.0001) Data generated by app allowed medical staff to track trends for patient and not only improve recognition of elevated BP, but observe

					BP represented an isolated event or if the patient has had multiple elevated BP. It doesn't provide further recommendations re: pt. management		whether elevated BP was isolated event.	
13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37	Wolf et al., 2016	Sweden	Hospital, outpatients' clinics and primary care patients <75yrs, English speaking	Investigate the effect of a web and mobile based eHealth diary and symptom tracking tool combined with a person-centred care intervention in patients hospitalised for an acute coronary syndrome event	Sub study of a randomized control trial Person centred care after Acute Coronary Syndrome(PACS) I Investigating the effects of person centred care in patients hospitalized with acute coronary syndrome One hundred and ninety-nine participants (n= 94 in intervention group and n= 105 in control group) Pt had option to use the webpage or the mobile app or both	App consisted of 3 modules: 1) self-rated fatigue scale 2) symptom trend graph 3) build in accelerometer within the phone to provide a daily average of the patients' physical activity level Webpage had 5 modules 1) self-rated symptoms of fatigue 2) symptom trend graph 3) diary function for free text entries to capture every day experience 4) chat function with other patients and registered nurses within the study 5) personal links to relevant webpages and ability to upload documents	Numerical Textual Graphical	Self-efficacy scale results indicate that use of the app improved patient self-efficacy. Small sample size only 37/90 patients participated (40% of patients included in intervention) All results classified as eHealth so unable to determine effect of the app vs. webpage Patients who used the eHealth tool in combination with person centred care intervention had 4-fold improvement compared to the control group.

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				Used the General Self Efficacy Scale (GSES) to evaluate patient-reported scores at baseline, 4 weeks, 8 weeks and 6 months			
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For Peer Review

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Table 3. Functions of apps

Communication	Illness management	Clinical management	Education/information
Messaging (Cingi et al., 2015; Holmen et al., 2017; Khanna et al., 2015; Kitsiou et al., 2017; Lee et al., 2015; Patel et al., 2016; Peiris et al., 2014; Sundberg et al., 2017)	Medication compliance (Lakshminarayana et al., 2017; Peiris et al., 2014)	Patient assessment (Dickson et al., 2016)	Disease information (Lakshminarayana et al., 2017; Lee et al., 2015; Peiris et al., 2014)
Image exchange (Armstrong et al., 2017; Gunter et al., 2016)	Symptom tracking (Holmen et al., 2017; Kitsiou et al., 2017; Wolf et al., 2016)	Decision making (Dickson et al., 2016) (Foo et al., 2015; Peiris et al., 2014)	Treatment information (Holmen et al., 2017; Jakel et al., 2016; Lee et al., 2015)
Discussion (Khanna et al., 2015)	Diet and activity (Kitsiou et al., 2017) (Wolf et al., 2016)	Symptom recognition (Christiansen, Fjell, & Sundberg, 2017; Sundberg et al., 2017; Twichell et al., 2017)	Illness management (Holmen et al., 2017; Kitsiou et al., 2017; Peiris et al., 2014)
Real-time feedback/advice (Holmen et al., 2017) (Kitsiou et al., 2017; Semple et al., 2015; Sundberg et al., 2017)	Post op recovery (Armstrong et al., 2017; Gunter et al., 2016; Semple et al., 2015; Sundberg et al., 2017)	Diagnosis (Twichell et al., 2017)	Data collection (Peiris et al., 2014)
Diary function (Cingi et al., 2015) (Gernart et al., 2017; Lee et al., 2015; Wolf et al., 2016)	Symptom burden (Macpherson et al., 2014; Sundberg et al., 2017)	Electronic health record (Lee et al., 2015; Peiris et al., 2014)	
Electronic health record (Lee et al., 2015; Peiris et al., 2014)	Quality of life (Cingi et al., 2015; Gernart et al., 2017; Jakel et al., 2016; Lee et al., 2015; Sundberg et al., 2017)	Handover (Khanna et al., 2015)	
	Self-monitoring (Jakel et al., 2016; Kitsiou et al., 2017; Lakshminarayana et al., 2017; Peiris et al., 2014; Wolf et al., 2016)	Digitisation of patient journey (Foo et al., 2015)	
	Reminders (Holmen et al., 2017; Jakel et al., 2016; Kitsiou et al., 2017; Lakshminarayana et al., 2017; Peiris et al., 2014)	Task performance (Foo et al., 2015)	
	Pain assessment (Semple et al., 2015)	Follow up (Armstrong et al., 2017; Gunter et al., 2016; Semple et al., 2015)	
	Diary function (Gernart et al., 2017) (Wolf et al., 2016)		

Note: The reference in Table 3 are of the 19 studies included in this review