Special Article

Wearable Technologies in Post-Operative Recovery: Clinical Applications and Positive Impacts

Petros Kolovos, RN, MSc, PhD
Assistant Professor, Laboratory of Integrated Health Care, Department of Nursing, University of Peloponnese, Tripolis, Greece

Correspondence: Petros Kolovos, Assistant Professor, Laboratory of Integrated Health Care, Department of Nursing, University of Peloponnese, Tripolis, Greece Email: pkolovos@uop.gr

Abstract

The perioperative setting is a complex and technologically advanced environment and new technologies have been implemented across the perioperative pathway as a mean to improve the quality and safety of the surgical care. The aim of the current review was to describe and highlight the clinical applicability of the wearable devices in postoperative recovery and to provide a comprehensive synthesis of their positives impacts. Wearable technologies are evident to have an input in the postoperative period mainly in activity and functional capacity monitoring, as well as in monitoring of patient's vital functions. The impact these devices have on the care process, the surgical patient and the care setting is promising, while further research is needed to establish their clinical efficiency. Management of postoperative recovery is a major concern for patients undergoing surgical procedures and for the care organizations. With the support of wearable technologies a patient-centered care is ensured in postoperative recovery and more evidence-based practice should be encouraged.

Keywords: wearable technologies, wearable devices, sensors, surgical procedures, postoperative care, postoperative recovery, rehabilitation, m-health

Introduction

A growing interesting in consumer market and medical research has emerged over the last years from the implementation of wearable technologies or "wearables" in healthcare settings. Mobile technologies such as applications (apps), wearable technologies and medical devices (referred to as mobile health or mHealth) have been developed to support health and social care by delivering health related information, recourses and remote services. Mobile technologies are based on the information and communication technologies and are described with the broad term e-health (Free et al. 2013; WHO 2016). E-health and the recent advances in digital technology, have an impact on reforming the organization culture of health care systems due to the challenges they face and should be effectively addressed. Moreover, e-health facilitates an effective communication, not only among interdisciplinary teams, but also between them and the patients in a complex health care system and promotes further research initiatives (WHO; WHO 2016).

Background

Wearable technologies encompass a wind range of electronic devices that are attached to the human body via personal equipment or other devices. Wearables with their basic components (the hardware, the software and a mobile phone or a computer application) possess computational capability with the ability to retrieve and present the data collected in real time or retrospectively (Slade Shantz & Veillette 2014). Based on a single type or multiple types of sensors, wearable devices are used for diagnosing and monitoring. Their capabilities include applications for physiological, biochemical and motion sensing (Patel et al. 2012).

Wearable devices have become of growing interest in the medical encounter and a large body of literature has been published over the last decades describing the clinical applications of these technologies. Most of them are used to monitor and provide feedback among healthy individuals and group of patients, covering aspects such as health and wellness, safety, rehabilitation, assessment of treatment efficacy and early detection of disorders (Patel et al. 2012; Wang et al. 2017; Bahadori, Immins & Wainwright 2018). Remote real time monitoring during home care and community care is feasible, which constitutes a supportive tool for the care providers in the framework of primary health care and enhances individual's independence (Soniyapriyadarshini, 2013).

Surgical care is an indispensable part of the healthcare provision and has a pivotal role to health and welfare improvement of the individuals. The need for surgical intervention covers a wind range of diseases categories which are attributed to conditions that are treated surgically (Meara et al. 2015). In addition, an increasing demand for surgical services is expected for elderly owing to the demographic changes which are associated with the ageing of the population (Liu et al. 2004). The perioperative setting is a complex and technologically advanced environment and emerging new technologies have been implemented across the perioperative pathway as a mean to improve the quality and safety of the surgical care (Stabile & Cooper 2013; Kolovos, Athanasopoulou, Tziaferi 2019). Slade Shantz and Veillette (2014) pointed out that wearable technology in surgical practice, has the potential role to assist, augment and provide a means of patient assessment.

Based on the growing interest of the researchers from different backgrounds and the clinicians for the deployment of wearable technologies in the context of clinical applications, this review follows two objectives: (1) to identify and highlight domains of clinical applicability of the wearable devices in postoperative recovery and (2) to provide a comprehensive synthesis of these technologies' positive impacts on the postoperative period.

Clinical applications

The review of the literature revealed empirical studies that document the implementation of the wearable technologies in postoperative recovery. The main clinical domains of wearable based technologies' applicability in postsurgical patients are describing as follow (Figure 1):

Activity and functional capacity monitoring:

Patients' functional status after surgery is a major determinant for recovery and an area that has most benefited from the technological advancements. Current evidence highlight that most studies have mainly been implemented to adult patients (Appelboom et al. 2015; Jeldi et al. 2016; Breteler et al. 2018; Kroll et al. 2017; Kim et al. 2019) or even elderly (Cook et al. 2013; Das et al. 2014), while pediatric patients undergoing elective surgical procedures (Ghomrawi et al. 2018) have also been in focus. The postoperative patient population included patients after elective (Aziz et al. 2011; Carandina et al. 2019; Carmichael et al. 2019; Wolk et al. 2019) or major (Cook et al. 2013; Daskivich et al. 2019) surgical procedures, cancer surgery (Low et al. 2017; Wu et al. 2019), total hip or knee arthroplasty surgery (Atallah et al. 2011; Kwasnicki et al. 2015; Jeldi et al. 2016; Chiang et al. 2017; Ramkumar et al. 2019), neurosurgery and spine surgery (Hogaboam & Daim 2018; Kim et al. 2019) and patients in post-surgery rehabilitation recovery (Rajanna et al. 2016; Gupta, Al-Anbuky & McNair 2018). Most studies conducted to inpatients during hospital recovery (Cook et al. 2013; Brown et al. 2014; Hogaboam & Daim 2018; Jeldi et al. 2016; Weenk et al. 2017; Kroll et al. 2017; Low et al. 2017; Daskivich et al. 2019; Kim et al. 2019; Wu et al. 2019), following by outpatients (Ghomrawi et al. 2018; Carmichael et al. 2019; Ramkumar et al. 2019). Community (Aziz et al. 2011; Gonzalez-Franco, Gilroy & Moore 2014; Kwasnicki et al. 2015; Carandina et al. 2019), as well as rehabilitation settings postoperatively (Atallah et al. 2011; Zhu et al. 2012; Appelboom et al. 2015; Rajanna et al. 2016; Gupta, Al-Anbuky & McNair 2018) were also included in the research interest for studying wearable devices' feasibility.

Monitoring of vital functions:

Continuous monitoring following surgery contributes to assess the clinical situation of the patient and to recognize them whose health status deteriorates clinically. On the other, frequently measurements of the vital signs increase workload for nursing staff while being discomfort to patients during hospitalization (Breteler et al. 2018). Empirical studies in the literature provide evidence for the continuous and/or remote monitoring in the postoperative period with the use of wearable technologies. The study population of these studies consisted of postsurgical patients at average (Brown et al. 2014; Das et al. 2014; Weenk et al. 2017) or high risk (Breteler et al. 2018) for complications, patients recovering from critical illness (Kroll et al. 2017) and post-operative patients discharged after surgery (Prettz et al. 2017; Carandina et al. 2019). The setting of these applications included inpatients (Brown et al. 2014; Das et al. 2014; Weenk et al. 2017; Breteler et al. 2018), critical care (Kroll et al. 2017) and postoperative follow-up (Prettz et al. 2017; Carandina et al. 2019).

Positive impacts on post-operative recovery

Analyzing and synthesizing the results of the evidence selected, wearable-based technologies postoperatively seem to have a positive impact on the (Figure 1):

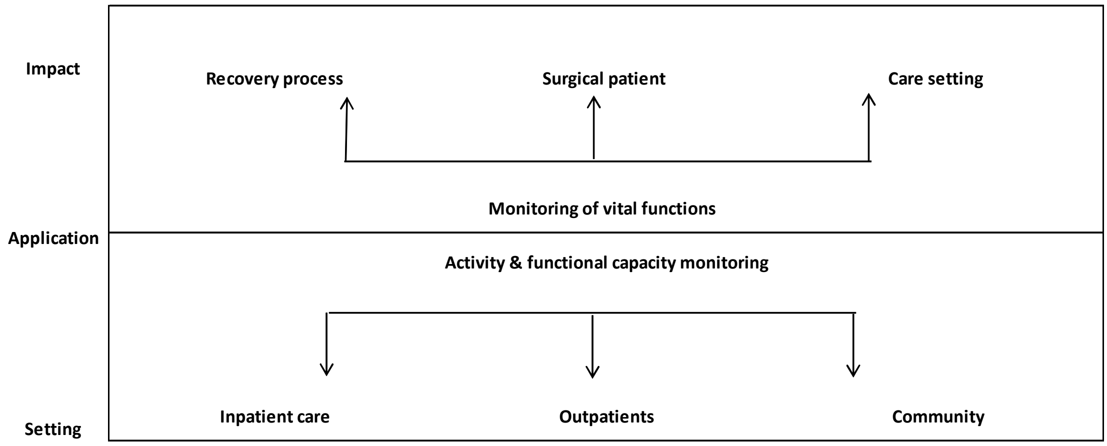

Figure 1. Wearable technologies in post-operative recovery: An outline of the applications and their impacts

***Recovery process*:** Wearable sensors constitute reliable continuous measurements (Cook et al. 2013; Jeldi et al. 2016; Chiang et al. 2017; Wu et al. 2019) of perioperative assessing, transforming physiological parameters to an objective and measurable ones. They facilitate timely and accurately measuring and recording of useful clinical data (Brown et al. 2014; Das et al. 2014; Prettz et al. 2017; Wu et al. 2019). In addition, they provide health related information during the perioperative period for decision-making, especially for patients at risk - facilitating early recognition of clinical changes and treatment, or of those that need additional either monitoring or interventions after surgery (Cook et al. 2013; Low et al. 2017; Agarwal et al. 2018; Hogaboam & Daim 2018). Moreover, monitoring in remote settings supports the recovery process (Das et al. 2014; Breteler et al. 2018; Ramkumar et al. 2019). They can wirelessly transmit data and facilitate follow-up, post-surgery rehabilitation and care in community settings postoperative (Aziz et al. 2011; Kwasnicki et al. 2015; Rajanna et al. 2016; Gupta, Al-Anbuky & McNair 2018; Carandina et al. 2019). Finally, these devices evaluate the process of the care provided and affect the postdischarge health outcomes (Brown et al. 2014; Cook et al. 2013; Kroll et al. 2017; Ghomrawi et al. 2018; Carandina et al. 2019).

***Surgical Patient*:** Wearable based technologies in postoperative recovery maximize and improve patients' performance and increase patients' compliance leading to improvements in health outcomes (Cook et al. 2013; Jeldi et al. 2016; Agarwal et al. 2018; Ramkumar et al. 2019; Wu et al. 2019). The implementation of an individualized postoperative care plan may be feasible and increases patient satisfaction of the receiving care (Breteler et al. 2018; Carmichael et al. 2019; Kim et al. 2019). In addition, independence after discharge is encouraged (Das et al. 2014; Rajanna et al. 2016; Breteler et al. 2018), which in turns promotes patient participation in self care activities.

***Care Setting*:** Wireless monitoring has been in focus of the health care organizations over the last decades as an attractive model of the recovery process. Wearable devices support surgical decision-making providing essential information for both patients undergoing surgery and health care providers (Kwasnicki et al. 2015). Furthermore, the wearable devices affect the rates of rehospitalization postoperatively (Atallah et al. 2011; Cook et al. 2013; Jeldi et al. 2016; Low et al. 2017; Wu et al. 2019) and have considered to be a predictor for the presence of complications and for the length of hospitalization for patients undergoing surgical procedures (Brown et al. 2014; Das et al. 2014; Carandina et al. 2019; Wolk et al. 2019). All this evidence affect the quality of the care provided improving the outcomes in perioperative practice, as well as the postdischarge outcomes and patient's follow-up (Cook et al. 2013; Kwasnicki et al. 2015).

Discussion

Wearable technologies are evident to have been integrated in post-operative recovery and have become a remarkable part of research directions in health care. These achievements provide a personalized care experience which in turn has a potential impact on satisfaction rates of the receiving services. The clinical efficacy of these technologies should further be examined in large scale clinical trials, while the economic burden for the care organizations remains a controversial matter that should also be addressed. In addition, the development of intelligent architectures for the integration of different types of sensors and the management of the clinical data obtained will be required when considering the needs for surgical patients in postoperative recovery. Mechanisms to guarantee a reliable functioning of the devices (Patel et al. 2012**)** and their acceptance should also be ensured. In their study, Weenk et al. (2017) found that wearable devices were well accepted from both patients and nurses which constitute a prerequisite for their implementation in clinical practice. Finally, security and confidentiality remain important aspects related with the use of m-health technologies in care settings and should be a priority for both researchers and clinicians.

Competences and skills for the different staff categories are also required for the use of the wearable technologies. Nurses' role has an obvious impact on the quality of the care provided in perioperative care since management of patient's mobility after surgery and recovery monitoring is of crucial importance for the nursing care. Nursing profession play a key role in the effort to integrate and implement these technologies in postoperative care. As a profession, Nursing should be willing to be innovative in the use of new technologies and devices to achieve quality improvement and patient safety (Yontz, Zinn & Schumacher 2015).

Conclusion

Management of postoperative recovery is a major concern for patients undergoing surgical procedures and care organizations with substantial implications for the individuals, the recovery process and the care setting. In a transforming healthcare system, there is adequate evidence that wearable technologies present a promising challenge to address issues related to the provision of postoperative feedback in monitoring both activity and functional recovery and patient's vital functions in terms of feasibility, quality, safety and a patient-centeredness approach of the care provided.

Even though the role of these technological achievements seems optimistic for the health care organizations in the near future, strategic priorities for further research for their efficiency in the perioperative period and post discharged are needed to establish clinical significance.

References

Agarwal DK., Viers BR., Rivera ME., Nienow, DA., Frank I., Tollefson MK., Gettman MT. (2018) Physical activity monitors can be successfully implemented to assess perioperative activity in urologic surgery. mHealth: 4.

Appelboom G., Taylor BE., Bruce E., Bassile CC., Malakidis C., Yang A., ... & Reginster JY. (2015) Mobile phone-connected wearable motion sensors to assess postoperative mobilization. JMIR mHealth and uHealth 3(3): e78.

Atallah L., Jones GG., Ali R., Leong JJ., Lo B., Yang, G Z. (2011) Observing recovery from knee-replacement surgery by using wearable sensors. In 2011 International Conference on Body Sensor Networks: 29-34.

Aziz O., Atallah L., Lo B., Gray E., Athanasiou T., Darzi A., Yang GZ. (2011) Ear-worn body sensor network device: an objective tool for functional postoperative home recovery monitoring. Journal of the American Medical Informatics Association 18(2): 156-159.

Bahadori S., Immins T., Wainwright TW. (2018) A review of wearable motion tracking systems used in rehabilitation following hip and knee replacement. Journal of rehabilitation and assistive technologies engineering 5: 2055668318771816.

Breteler MJ., Huizinga E., van Loon K., Leenen LP., Dohmen DA., Kalkman CJ., Blokhuis TJ. (2018) Reliability of wireless monitoring using a wearable patch sensor in high-risk surgical patients at a step-down unit in the Netherlands: a clinical validation study. BMJ open *8*(2): e020162.

Brown H., Terrence J., Vasquez P., Bates D.W., Zimlichman E. (2014) Continuous monitoring in an inpatient medical-surgical unit: a controlled clinical trial. The American journal of medicine 127(3): 226-232.

Carmichael H., Overbey DM., Hosokawa P., Goode CM., Jones TS., Barnett Jr CC., ... & Robinson TN. (2019) Wearable Technology—A Pilot Study to Define "Normal" Postoperative Recovery Trajectories. Journal of Surgical Research 244: 368-373.

Carandina S., Zulian V., Nedelcu A., Sista F., Danan M., Nedelcu M. (2019) Laparoscopic sleeve gastrectomy follow-up: use of connected devices in the postoperative period. Surgery for Obesity and Related Diseases 15(7): 1058-1065.

Chiang CY., Chen KH., Liu KC., Hsu S., Chan CT. (2017) Data collection and analysis using wearable sensors for monitoring knee range of motion after total knee arthroplasty. Sensors 17(2): 418.

Cook DJ., Thompson JE., Prinsen SK., Dearani JA., Deschamps C. (2013) Functional recovery in the elderly after major surgery: assessment of mobility recovery using wireless technology. The Annals of thoracic surgery 96(3): 1057-1061.

Das D., Pal A., Tewary S., Chakraborty S., Gupta SD. (2014) A Smart and Wearable Cardiac Healthcare System with Monitoring of Sudden Fall for Elderly and Post-Operative Patients. IOSR Journal of Computer Engineering 16(2): 126-133.

Daskivich TJ., Houman J., Lopez M., Luu M., Fleshner P., Zaghiyan K., ... & Kremen T. (2019) Association of Wearable Activity Monitors With Assessment of Daily Ambulation and Length of Stay Among Patients Undergoing Major Surgery. JAMA network open 2(2): e187673-e187673.

Free C., Phillips G., Watson L., Galli L., Felix L., Edwards P., Patel V., Haines, A. (2013) The effectiveness of mobile-health technologies to improve health care service delivery processes: a systematic review and meta-analysis. PLoS medicine 10(1): e1001363.

Ghomrawi HM., Baumann LM., Kwon S., Hebal F., Hsiung G., Williams K., ... & Abdullah F. (2018) Using accelerometers to characterize recovery after surgery in children. Journal of pediatric surgery 53(8): 1600-1605.

Gonzalez-Franco M., Gilroy S., Moore JO. (2014) Empowering patients to perform physical therapy at home. In 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society: 6308-6311.

Gupta A., Al-Anbuky A. & McNair P. (2018) Activity Classification Feasibility Using Wearables: Considerations for Hip Fracture. Journal of Sensor and Actuator Networks 7(4): 54.

Hogaboam L. & Daim T. (2018) Technology adoption potential of medical devices: The case of wearable sensor products for pervasive care in neurosurgery and orthopedics. Health Policy and Technology *7*(4): 409-419.

Jeldi AJ., Grant M., Allen DJ., Deakin AH., McDonald DA., Stansfield BW. (2016) Upright time and sit-to-stand transition progression after total hip arthroplasty: an Inhospital Longitudinal Study. The Journal of arthroplasty 31(3): 735-739.

Kolovos P., Athanasopoulou A., Tziaferi St. (2019) Emerging technologies in perioperative care: a literature review. Conference Abstracts: European Academy of Nursing Science Summer Conference 2019. BMC Nursing 18(Suppl 2):55.

Kroll RR., McKenzie ED., Boyd JG., Sheth P., Howes D., Wood M., Maslove D. M. (2017) Use of wearable devices for post-discharge monitoring of ICU patients: a feasibility study. Journal of intensive care *5*(1): 64.

Kim DH., Nam KH., Choi BK., Han I.H., Jeon TJ., Park SY. (2019) The Usefulness of a Wearable Device in Daily Physical Activity Monitoring for the Hospitalized Patients Undergoing Lumbar Surgery. Journal of Korean Neurosurgical Society 62(5): 561.

Meara JG., Leather AJ., Hagander L., Alkire BC., Alonso N., Ameh EA., ... & Mérisier ED. (2015) Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. The Lancet 386 (9993): 569-624.

Kwasnicki RM., Ali R., Jordan SJ., Atallah L., Leong JJ., Jones GG., ... & Darzi A. (2015) A wearable mobility assessment device for total knee replacement: A longitudinal feasibility study. International Journal of Surgery 18*:* 14-20.

Low CA., Bovbjerg DH., Ahrendt S., Choudry MH., Holtzman M., Jones HL., ... & Bartlett DL. (2017) Fitbit step counts during inpatient recovery from cancer surgery as a predictor of readmission. Annals of Behavioral Medicine 52(1): 88-92.

Liu JH., Etzioni DA., O'Connell JB., Maggard MA., Ko CY. (2004) The increasing workload of general surgery. Archives of Surgery 139 (4): 423-428.

Patel S., Park H., Bonato P., Chan L., Rodgers M. (2012) A review of wearable sensors and systems with application in rehabilitation. Journal of neuroengineering and rehabilitation *9* (1):21.

Prettz JB., da Costa JPC., Alvim JR., Miranda RK., Zanatta MR. (2017) Efficient and low cost MIMO communication architecture for smartbands applied to postoperative patient care. In 2017 Second Russia and Pacific Conference on Computer Technology and Applications (RPC): 1-5.

Rajanna V., Vo P., Barth J., Mjelde M., Grey T., Oduola C., Hammond T. (2016) KinoHaptics: An automated, wearable, Haptic assisted, physio-therapeutic system for post-surgery rehabilitation and self-care. Journal of medical systems 40(3): 60.

Ramkumar PN., Haeberle HS., Ramanathan D., Cantrell WA., Navarro SM., Mont MA., ... & Patterson BM. (2019) Remote Patient Monitoring Using Mobile Health for Total Knee Arthroplasty: Validation of a Wearable and Machine Learning–Based Surveillance Platform. The Journal of arthroplasty 34(10): 2253-2259.

Slade Shantz JA. & Veillette CJ. (2014) The application of wearable technology in surgery: ensuring the positive impact of the wearable revolution on surgical patients. Frontiers in surgery 1: 39.

Soniyapriyadarshini R. (2013) Case study on smart wearable sensors and systems with application in rehabilitation. International Journal of Scientific & Engineering Research 4: (5).

Stabile M. & Cooper L. (2013) The evolving role of information technology in perioperative patient safety. Canadian Journal of Anesthesia/Journal canadien d'anesthésie 60(2): 119-126.

Wang Q., Markopoulos P., Yu B., Chen W., Timmermans A. (2017) Interactive wearable systems for upper body rehabilitation: a systematic review. Journal of NeuroEngineering and Rehabilitation 14: 20.

Weenk M., van Goor H., Frietman B., Engelen LJ., van Laarhoven C J., Smit J., ... & van de Belt TH. (2017) Continuous monitoring of vital signs using wearable devices on the general ward: pilot study. JMIR mHealth and uHealth 5(7): e91.

Wolk S., Linke S., Bogner A., Sturm D., Meißner T., Müssle B., ... & Welsch T. (2019) Use of Activity Tracking in Major Visceral Surgery—the Enhanced Perioperative Mobilization Trial: a Randomized Controlled Trial. Journal of Gastrointestinal Surgery 23(6): 1218-1226.

WHO. (2016) From innovation to implementation eHealth in the WHO European Region. [Accessed December 2019]

WHO. E-health. [Accessed December 2019]

Wu JM., Ho TW., Chang YT., Hsu C., Tsai CJ., Lai F., Lin MT. (2019) Wearable-Based Mobile Health App in Gastric Cancer Patients for Postoperative Physical Activity Monitoring: Focus Group Study. JMIR mHealth and uHealth 7(4): e11989.

Yontz LS., Zinn JL., Schumacher EJ. (2015) Perioperative nurses' attitudes toward the electronic health record. Journal of PeriAnesthesia Nursing 30(1): 23-32.

Zhu Y., Nakamura M., Ito N., Fujimoto H., Horikuchi K., Wakabayashi S., ... & Haro H. (2012) Study of wearable knee assistive instruments for walk rehabilitation. Journal of Advanced Mechanical Design, Systems and Manufacturing 6(2): 260-273.