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Case Report

Using smartphone-based accelerometers to gauge postoperative outcomes in patients with NPH: Implications for ambulatory monitoring

Annelise Claire Sprau[1], Gregory W. Basil[1], Karen Eliahu[1], Frederic A. Vallejo[1], Evan M. Luther[1], Jang W. Yoon[2], Michael Y. Wang[1], Ricardo J. Komotar[1]

[1]Department of Neurological Surgery, University of Miami, Miami, Florida, [2]Department of Neurological Surgery, University of Pennsylvania, Philadelphia, Pennsylvania, United States.

E-mail: Annelise Claire Sprau - annelise.sprau@med.miami.edu; Gregory W. Basil - gregory.basil@jhsmiami.org; Karen Eliahu - kareneliahu@med.miami. edu; Frederic A. Vallejo - fav8@med.miami.edu; Evan M. Luther - evan.luther@jhsmiami.org; Jang W. Yoon - jwyoon226@gmail.com; Michael Y. Wang - mwang2@med.miami.edu; *Ricardo J. Komotar - rkomotar@med.miami.edu

***Corresponding author:**
Dr. Ricardo J. Komotar,
Department of Neurological Surgery, University of Miami, Miami, Florida, United States.

annelise.sprau@med.miami.edu

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ABSTRACT

Background: The surgical treatment of normal pressure hydrocephalus (NPH) with shunting remains controversial due to the difficulty in distinguishing such pathology from other neurological conditions that can present similarly. Thus, patients with suspected NPH should be carefully selected for surgical intervention. Historically, clinical improvement has been measured by the use of functional grades, alleviation of symptoms, and/or patient/family-member reported surveys. Such outcome analysis can be subjective, and there is difficulty in quantifying cognition. Thus, a push for a more quantifiable and objective investigation is warranted, especially for patients with idiopathic NPH (INPH), for which the final diagnosis is confirmed with postoperative clinical improvement. We aimed to use Apple Health (Apple Inc., Cupertino, CA) data to approximate physical activity levels before and after shunt placement for NPH as an objective outcome measurement. The patients were contacted and verbally consented to export Apple Health activity data. The patient's physical activity data were then analyzed. A chart review from the patient's EMR was performed to understand and better correlate recovery.

Case Description: Our first patient had short-term improvements in activity levels when compared to his preoperative activity. The patient's activity level subsequently decreased at 6 months and onward. This decline was simultaneous to new-onset lumbar pain. Our second patient experienced sustained improvements in activity levels for 12 months after his operation. His mobility data were in congruence with his subjectively reported improvement in clinical symptoms. He subsequently experienced a late-decline that began at 48-months. His late deterioration was likely confounded by exogenous factors such as further neurodegenerative diseases coupled with old age.

Conclusion: The use of objective activity data offers a number of key benefits in the analysis of shunted patients with NPH/INPH. In this distinctive patient population, detailed functional outcome analysis is imperative because the long-term prognosis can be affected by comorbid factors or life expectancy. The benefits from using smartphone-based accelerometers for objective outcome metrics are abundant and such an application can serve as a clinical aid to better optimize surgical and recovery care.

Keywords: Idiopathic normal pressure hydrocephalus, Normal pressure hydrocephalus, Outcome analysis, Smartphone accelerometer, Ventriculoperitoneal shunt

INTRODUCTION

The term normal pressure hydrocephalus (NPH) was first coined by Adams *et al.* in 1965 to describe a clinical syndrome defined by the triad of psychomotor retardation, urinary incontinence, and progressive cognitive impairment.[1] NPH is associated with hydrocephalus and normal range cerebrospinal fluid (CSF) pressure on lumbar puncture (LP). There are multiple pathologies which are thought to lead to NPH,[16] and nearly half of patients with NPH have no identifiable risk factors and are thus deemed to have idiopathic NPH (INPH).[11] The surgical treatment of INPH with shunting remains controversial as there is significant difficulty in distinguishing such pathology from other neurological conditions that can produce symptoms of NPH (e.g. vascular dementia and Parkinson's disease).[5,18] Such coexisting medical conditions in the elderly population do not respond to shunting, thus patients with suspected INPH should be carefully selected for surgical intervention.

On the contrary, the gold-standard for treating primary NPH involves the surgical placement of a shunt. Reported outcomes within the pertinent literature suggest that up to 80% of patients with NPH will respond to CSF shunting, versus 37% of patients with INPH.[4] However, the timing and durability of this benefit remain unclear. In light of these reported outcomes, we must carefully select patients for surgical intervention and develop a reliable method to measure the post-surgical outcomes and extent of clinical improvement versus more conservative management.[9]

To date, the outcome-based literature for postoperative improvement has been distorted by varying definitions of clinical improvement, differences in postoperative follow-up, and the presence of comorbid medical conditions.[9] Historically, clinical improvement in these patients has been measured by use of functional grades, alleviation of symptoms based on consensus between the neurosurgeon and patient, and/or patient/family-member reported surveys.[14] Such outcome analysis may be challenging due to its subjective nature, and the difficulty in quantifying a complex, multi-dimensional variable such as cognition. In addition, these subjective questionnaires are temporally limited to specific time points when they are filled out; therefore, they fail to capture functional outcomes during intervening time. Thus, a push for a more quantifiable and objective investigation is warranted, especially for patients with INPH, for which the final diagnosis is confirmed when clinical improvement is seen in the postoperative period.[12]

In this case report, we outline the clinical course of two patients with NPH and utilize their Apple Health Data (Apple Inc., Cupertino, CA) for objective postoperative recovery analysis. This is, to the best of our knowledge, the first report of using a smartphone-based accelerometer to approximate physical activity in the pre- and post-operative period for patients with NPH.

MATERIALS AND METHODS

All patients who underwent surgery for NPH between 2013 and 2020 by a single senior cranial surgeon at a large academic center were included in the study. There were no exclusionary criteria. The patients were contacted and verbally consented by a member of our research team through the telephone following our Institutional Review Board protocol.[13] Written instructions were provided on how to download the application "QS Access" (Quantified Self Labs, San Francisco, CA). This free application exports Apple Health activity data. The patient was directed to send their downloaded data to a secure email address. Once received, all personal health information was removed and the patient was assigned a unique identifier which was used to save their health data. The patient's physical activity data were then imported into a Microsoft Excel spreadsheet for processing an analysis. In addition, a chart review from the patient's electronic medical record (EMR) was performed to understand and better correlate the patient's activity decline.

CASE REPORTS

Patient 1

A 76-year-old male presented to the emergency room with slowly progressive gait difficulty, motor retardation, and generalized "weakness." The patient otherwise had no relevant past medical history. Computed tomography (CT) and magnetic resonance imaging were performed which demonstrated prominent lateral ventricles out of proportion to the degree of cortical sulcal markings [Figure 1]. The patient was seen by the neurology service due to a broad differential diagnosis including Parkinson's disease; however, following clinical evaluation, NPH was thought to be the most likely diagnosis. A high-volume LP was then performed and resulted in significant improvement in the patient's gait. Based on his clinical presentation, his excellent response

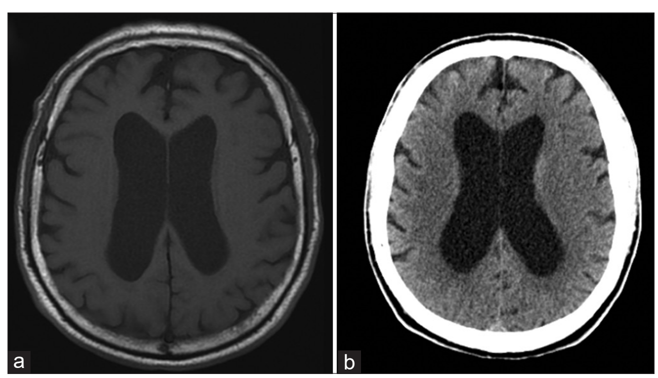

Figure 1: Preoperative T1-weighted non-contrast axial magnetic resonance imaging (a) and non-contrast axial computed tomography (b) demonstrating prominent lateral ventricles out of proportion to degree of cortical sulcal markings suggestive of hydrocephalus.

to CSF drainage, and after ruling out other coexisting neurological disorders, the patient was diagnosed with INPH and was scheduled for surgical intervention with a ventriculoperitoneal (VP) shunt placement. The patient underwent a right VP shunt placement with neuronavigation with a Strata valve set to 2.0 and tolerated the surgery well without complications. Postoperative imaging demonstrated a reduction in the amount of ventricular dilatation [Figure 2].

During his 2-week follow-up visit, the patient reported improvement in his gait, cognition, and incontinence. In his 3-month follow-up visit the patient reported episodic low back pain, but his clinical symptoms from the INPH remained stable and his valve setting was therefore left at 2.0. A timeline of the distance and steps walked by the patient over the span of 1 year preoperatively to 1 year postoperatively demonstrated a progressive decline in activity which continued following surgical intervention [Figure 3].

Figure 2: Postoperative non-contrast axial computed tomography demonstrating the placement of a right parietal approach ventriculoperitoneal shunt with a reduction in hydrocephalus as compared to prior scan.

Patient 2

A 70-year-old male presented with a 2-month history of cognitive slowing, bladder dysfunction, and gait imbalance. The patient additionally reported a history of chronic lower back pain, benign prostatic hyperplasia, and a right total knee replacement 8 months prior. After clinical evaluation and CT imaging, he was found to have INPH and was referred for right VP shunt placement [Figure 4]. The patient underwent an uncomplicated right VP shunt placement with a Strata valve set to 2.0 and tolerated the procedure well [Figure 5].

At his 2-week follow-up visit, the patient self-reported that his walking has improved since surgery. He did report some fatigue but attributed this to his right total knee replacement. He additionally reported an improvement in both urinary continence and cognition. At this time, the Strata valve was dilated to 1.5 in attempt to further symptomatic improvement. During his 1-month postoperative visit, he reported further improvement in walking and urinary incontinence and his valve was therefore left at 1.5. A timeline of the distance and steps walked by the patient over the span of 1 year preoperatively to 1 year postoperatively demonstrated a transient, but significant improvement in activity following surgery which was sustained until approximately week 47, after which patient experienced progressive activity decline [Figure 6].

DISCUSSION

In this case report, we present the clinical course of two patients with INPH who underwent surgical intervention with a shunt placement. We believe this small sample size is

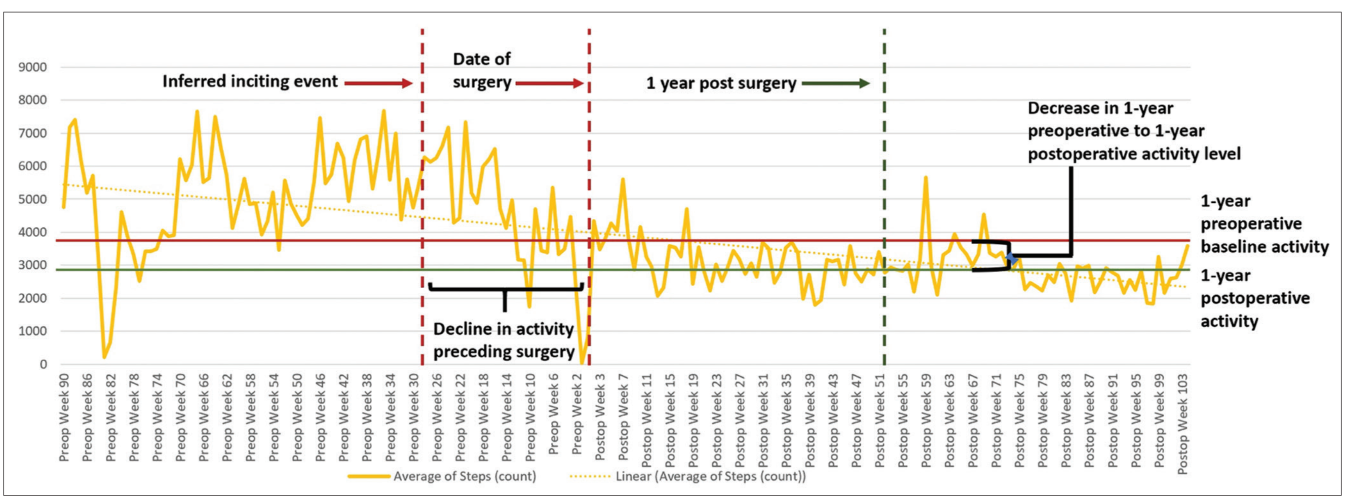

Figure 3: Graph of patient one's daily average steps taken by week demonstrating key milestones and benchmarks.

Figure 4: Preoperative non-contrast axial computed tomography demonstrating enlargement of the ventricles out of proportion to the sulcal prominence. There is crowding of the sulci near the vertex as well as an acute callosal angle.

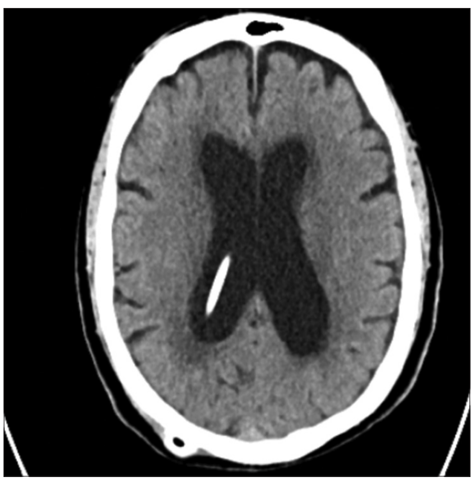

Figure 5: Postoperative non-contrast axial computed tomography demonstrating a right parietal ventriculoperitoneal shunt placement and a mild decrease in the dilatation of the temporal horns as well as the lateral ventricles.

likely related to patient demography, for which many patients in our cohort did not own smartphones or had caretakes that had smartphones in their place. Nevertheless, to the best of our knowledge, this is the first report correlating patient with NPH's daily physical activity extrapolated from an iPhone application to events described in the EMR.

Over the years, there have been numerous reports on patient outcomes following shunting for both NPH and INPH in attempt to clarify the exact criteria for surgical intervention.[10,15] Such studies have used a wide variety of lengths of follow-up and different assessment tools to evaluate functional status. Consequently, the outcomes also have differed markedly. To date, clinical improvement has been measured by reported scales on cognition, patient-reported daily functioning levels, gait analysis, radiographic, and physiologic measures.[3]

Notably, one of the cardinal features of NPH is gait impairment. There have been few studies investigating the realm of accelerometer-based mobility assessment in surgically treated NPH patients. Gaglani *et al.* sought to examine the use of commercial activity monitors (i.e. Fitbit Ultra, Nike Fuelband) for postoperative analysis. In their sample population, they compared the step count recorded by activity monitors to and observed step count for a 10-m walking trial.[6] The authors concluded that the Fitbit Ultra provides the most accurate gait measurement. However, while this study may have been useful for understanding the fidelity of accelerometer activity measurement, it did not necessarily address the clinical application. Indeed, while these findings underscore the potential of stand-alone accelerometers in the postoperative assessment of patients with shunt-treated NPH/INPH, such methods require both patient compliance and an additional capital expenditure.

Fortunately, the modern smartphone technology enables us to conveniently capture mobility data in an unbiased and retrospective measure (Basil *et al.*, 2021).[2] Further, this suggests a mechanism by with physicians can monitor patients prospectively. While NPH/INPH patients traditionally see their physicians at certain pre-determined and arbitrary intervals, continuous monitoring can lend further insight into a patient's recovery, or setback. Early detection of a change in motor activity, a cardinal feature of the NPH/INPH triad, could prompt physicians to aid in mitigating or even reversing the impact on patient well-being. For example, the after a detected decline in physical activity, the patient could be seen earlier in clinic for full examination and possible shunt setting alteration. Alternatively, a decline in activity may suggest the existence of additional medical comorbidities or the need for additional physical/occupational therapy.

Moreover, practices are presented with unique challenges across many medical fields during the evolving pandemic, forcing numerous institutions to move feasible care to a virtual platform. In our own experiences, outpatient neurosurgery is no exception, and as we increasingly shift toward a telehealth platform. Although the importance of an in-person physical exam cannot be undermined, virtual objective analysis can serve to positively augment telehealth visits.

Patient activity data

Our first patient had marked short-term improvements in activity levels when comparing his activity 2 weeks preoperatively to 2 weeks postoperatively. The patient's activity level subsequently decreased at 6 months and onward.

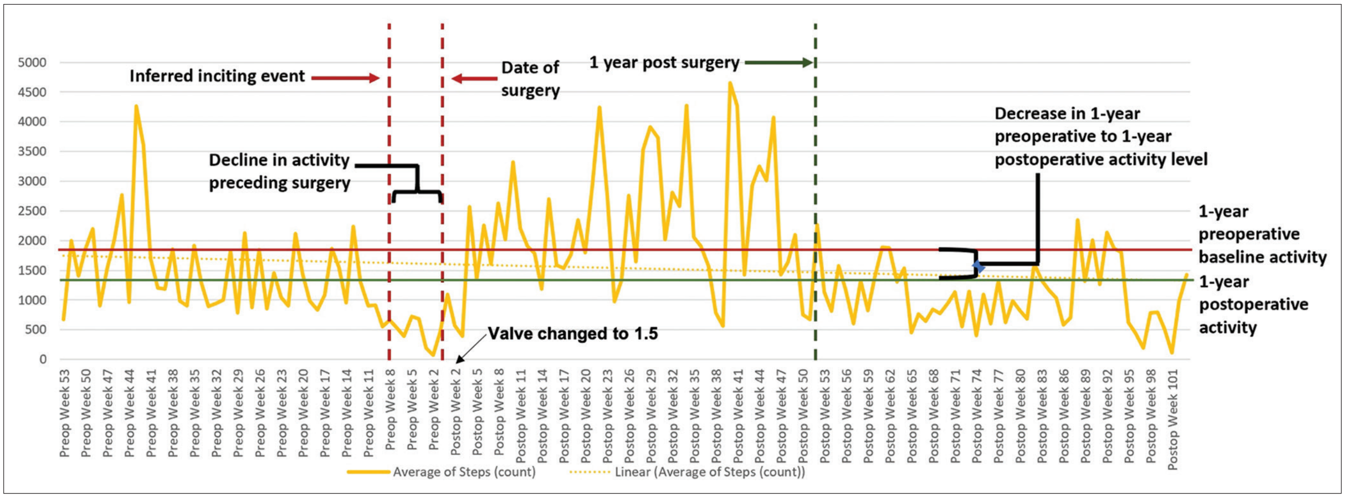

Figure 6: Graph of patient two's daily average steps taken by week demonstrating key milestones and benchmarks.

This finding is interesting and has numerous potential explanations. These explanations include (1) misdiagnosis, (2) inappropriate shunt settings, (3) additional undiagnosed neurologic pathologies, or (4) natural history of NPH. While an increase in physical activity levels can be correlated with a patient's surgical benefits, these objective metrics can likewise lend insight into postoperative decline. Our first patient is a perfect example of this capacity. After our patient started reporting episodic back pain, his physical activity began to decline simultaneously. While it is not possible to fully attribute his decline to lumbar pathology, it does suggest the need for further evaluation and potential treatment of this patient to develop a holistic understanding of his condition.

Our second patient experienced sustained improvements in activity levels when comparing his activity 2 weeks preoperatively to 2 weeks, 6 months, and 12 months postoperatively. His mobility data were in congruence with his subjectively reported improvement in clinical symptoms, as correlated through the EMR. He subsequently experienced a late-decline that began at 48-month postoperatively and persisted thereafter. This finding is especially noteworthy as a certain proportion of patients develop a second clinical deterioration after initial improvement in clinical symptoms.[7] In the pertinent literature, up to 20% of patients will experience secondary deterioration, with some amendable to shunt management and/or shunt revision.[8] On examination, our patient did not report a worsening in symptoms, so the shunt settings were held at 1.5. Thus, he was considered as a "secondary non-responder" to shunt intervention, meaning his late deterioration is likely confounded by exogenous factors such as further neurodegenerative diseases coupled with senescence.

The use of objective activity data offers a number of key benefits in the postoperative analysis of patients who have underwent shunt placement for NPH/INPH. In this distinctive patient population, detailed functional outcome analysis is imperative because the long-term prognosis of shunting can be affected by comorbid factors or life expectancy. In addition, because "gait dysfunction" is a pier in the clinical triad of NPH/INPH, objective movement analysis can lend insight to clinical improvement and aid in clinician's' management of shunt settings.[7] Further, considering that the operative definition of INPH has been postoperative response to CSF shunting, much detail has been focused on elucidating clinical factors that will predict which patients will respond to surgical intervention.[11] The benefits from using smartphone-based accelerometers for objective outcome metrics are abundant, but perhaps most importantly, such an application can serve as a clinical aid to better optimize surgical and recovery care.

Given the novelty of objective, smartphone-based activity assessment, further research will be required to fully validate these methods. First, there will undoubtedly be questions regarding the accuracy and fidelity of smartphone-based accelerometer data. Fortunately, there are previous studies which address this question.[17] Indeed, while certain activities will undoubtedly overstate or understate true patient activity, we believe that these discrepancies will ultimately "wash-out" in the extremely large and rich dataset collected. Nevertheless, it would be useful to conduct future studies where observed and actual activity data are compared to understand the magnitude of these discrepancies in this particular patient population. Such studies would be ideally suited for an inpatient setting. In addition, in an older patient population, we also must consider the possibility that caretakers and the patients themselves are carrying the phones. This shortcoming, however, could easily be addressed by a survey where participants respond as to whether they, or their caregiver, are routinely in possession of their phone.

While a formal survey was not performed for this particular study, both patients who participated reported that they were typically in possession of their phones.

CONCLUSION

The pertinent literature demonstrates that placing a shunt as a treatment for NPH/INPH may yield varied results. Historically, postoperative outcomes are reported utilizing survey metrics which may be subjective, and often confounded by other co-existing medical conditions in this specific patient population. Ultimately, this calls for an objective outcome metric to augment clinical evaluation in the postoperative period. Our experience with utilizing smartphone accelerometer data from this report suggests short-term and long-term evaluation in activity levels can be used in conjunction with the EMR to better approximate surgical success and guide in postoperative care.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Nil.

Conflicts of interest

Dr. Gregory Basil: Co-founder and direct stock ownership in Kinesiometrics LLC Dr. Jang Yoon: Co-founder and direct stock ownership in Kinesiometrics LLC and Medcyclops LLC Dr. Michael Wang: Consultant for DePuy Synthes Spine, K2M, Stryker, and Spineology; patent holder with DePuy Synthes Spine; direct stock ownership in ISD, Medical Device Partners. Co-founder and direct stock ownership in Kinesimoetrics LLC.

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